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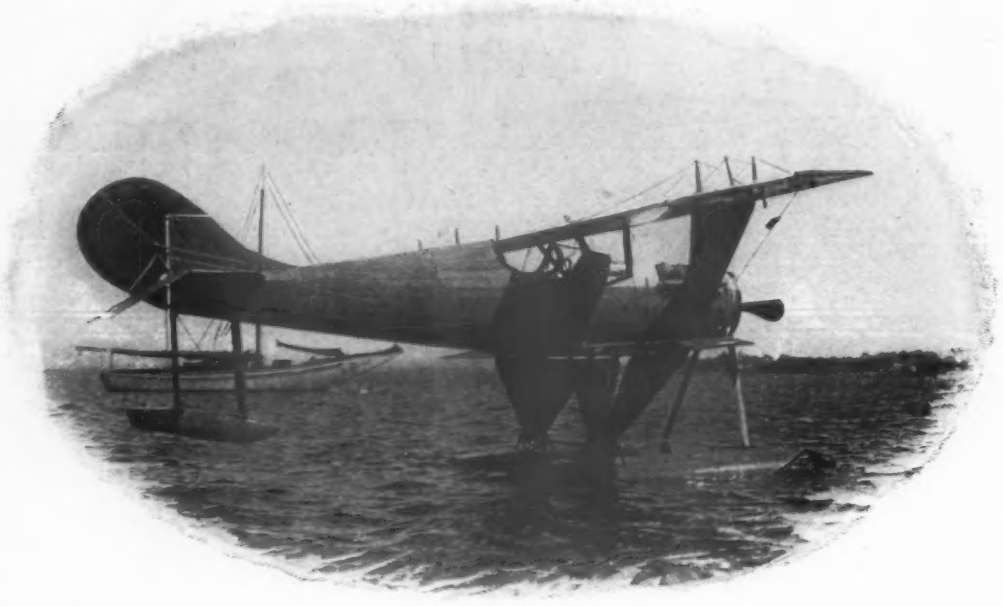

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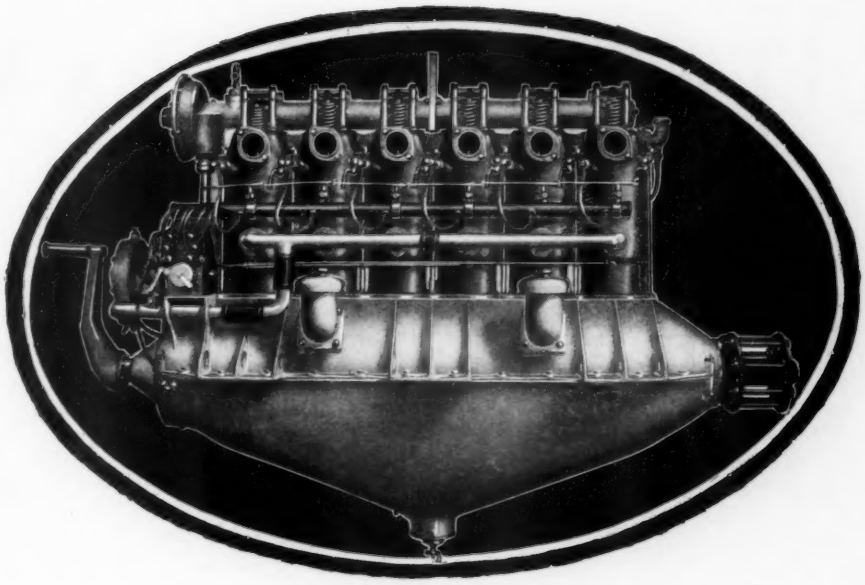

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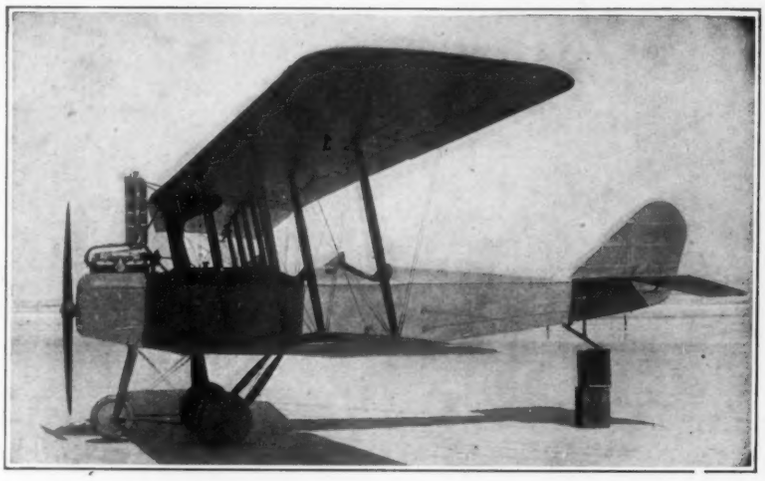

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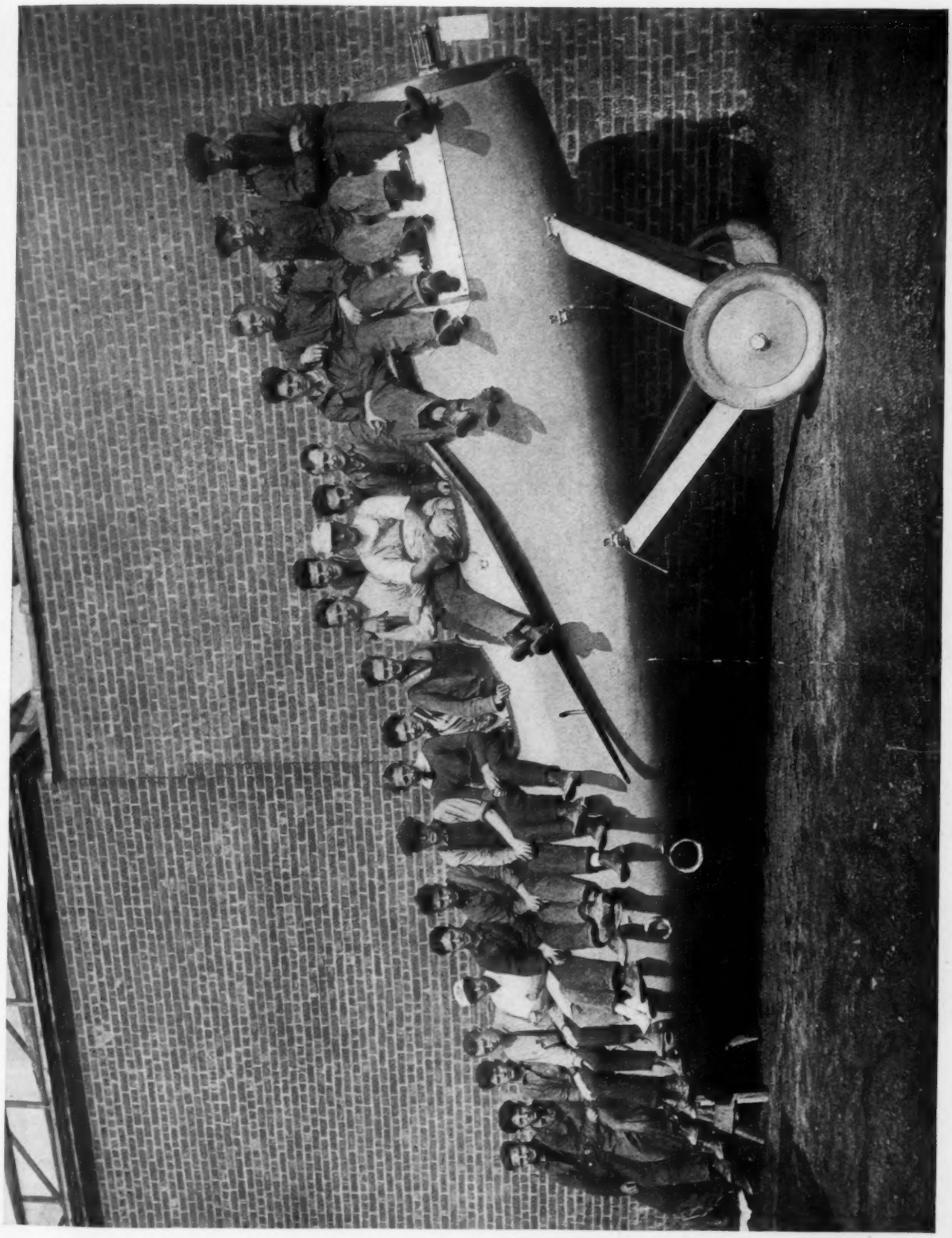

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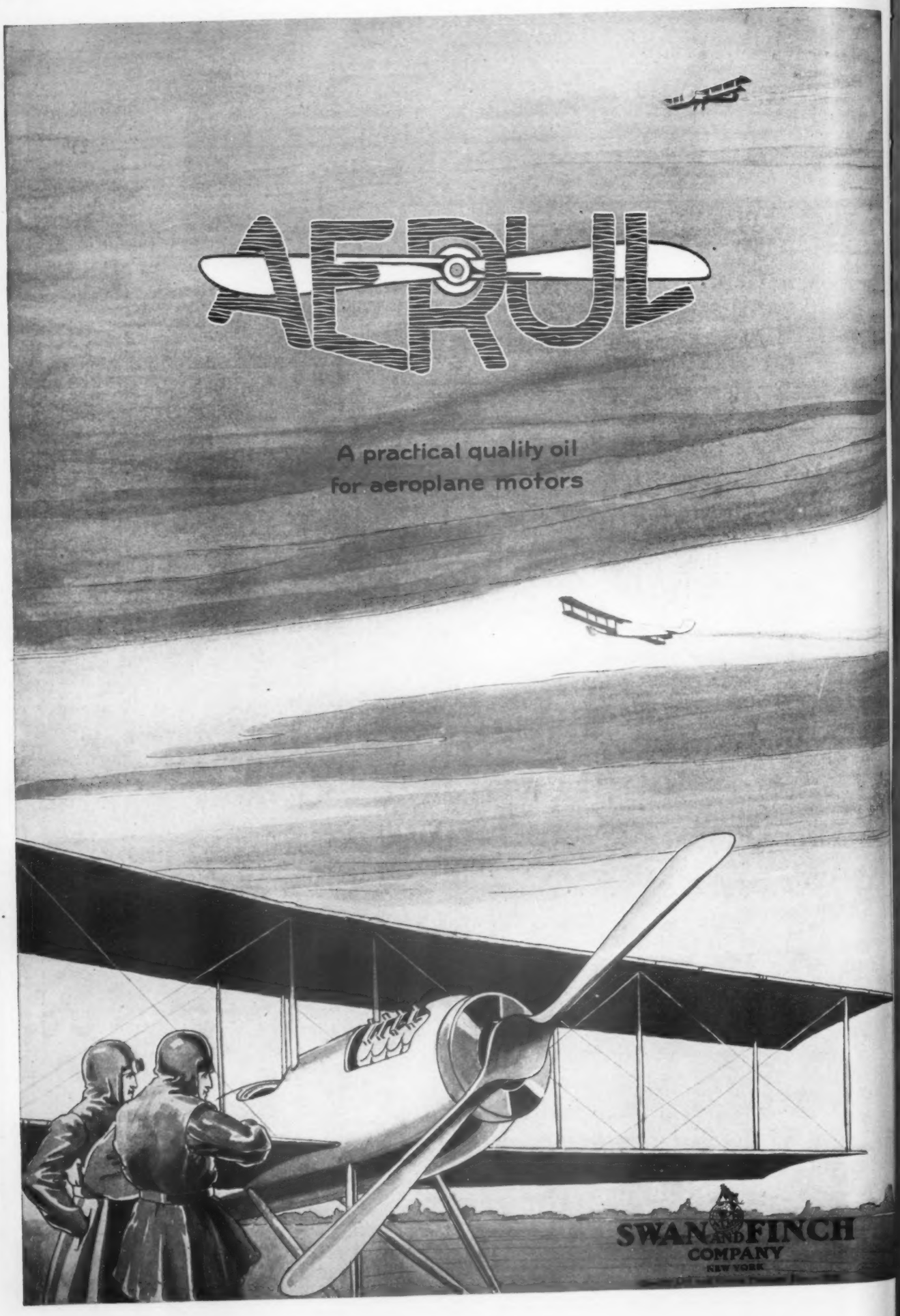
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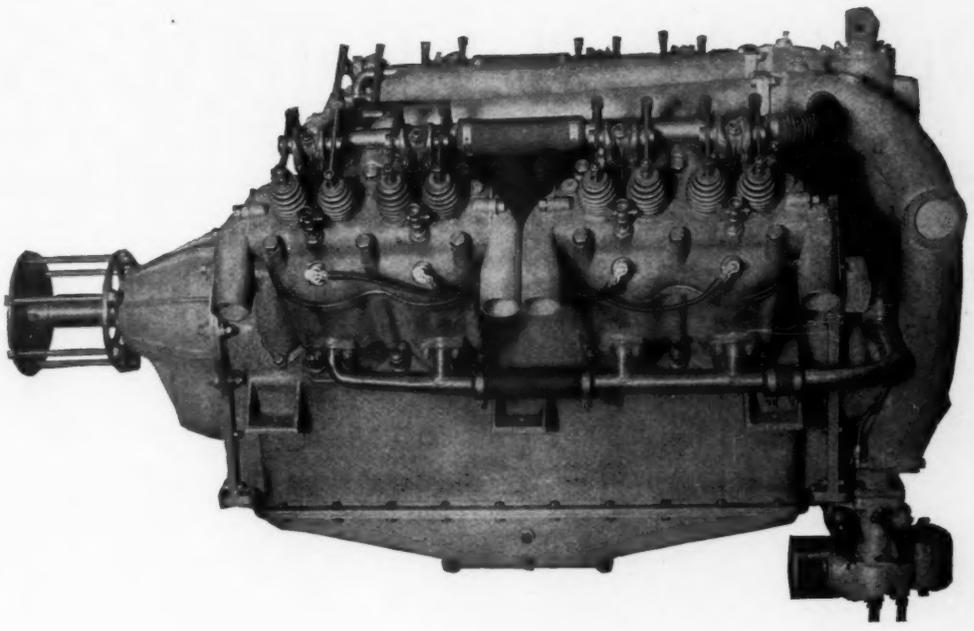

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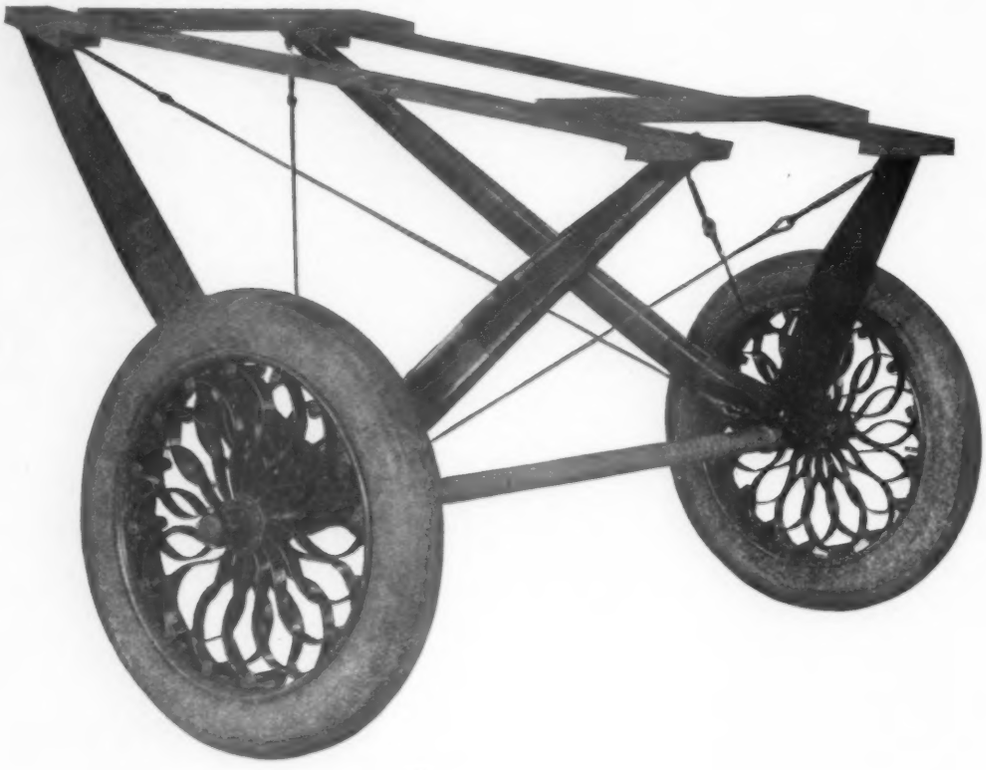

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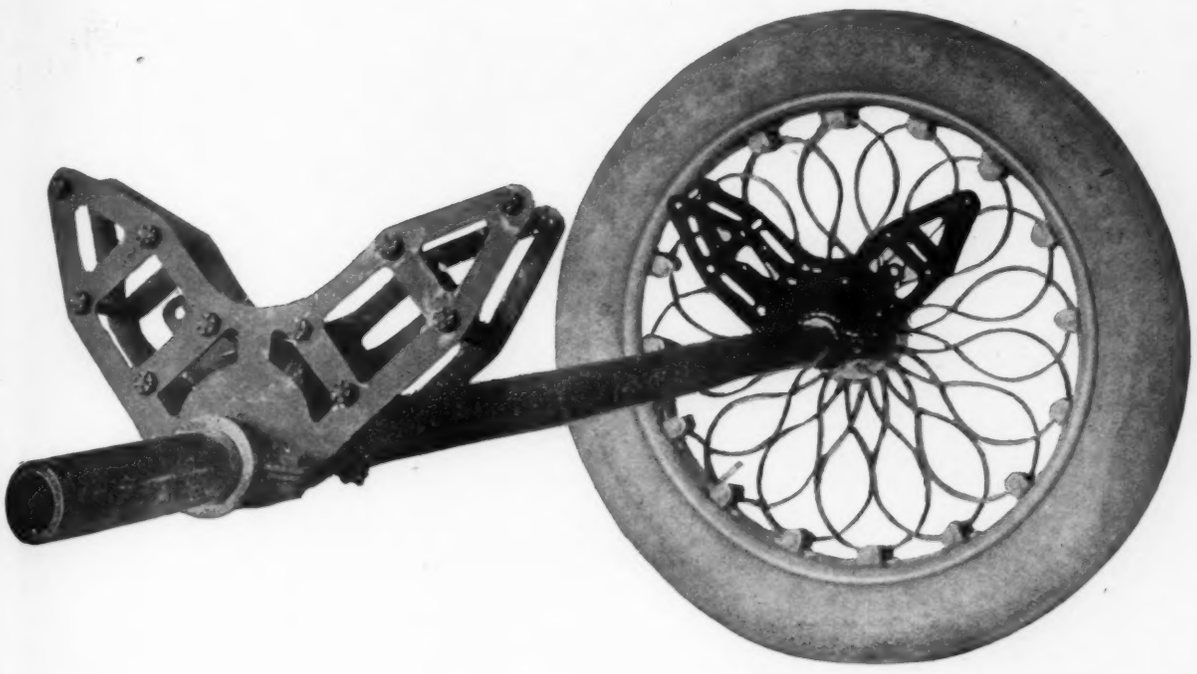

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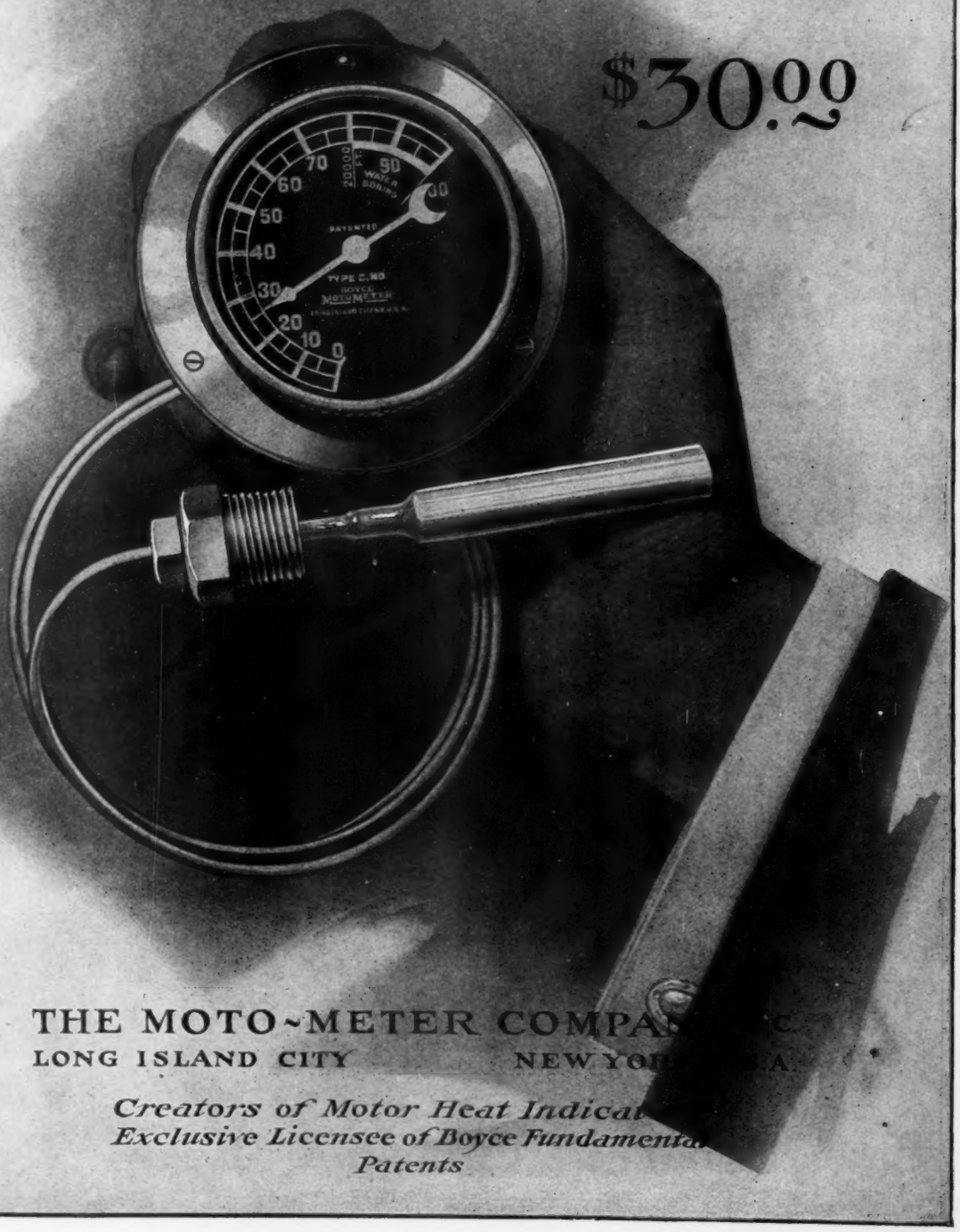

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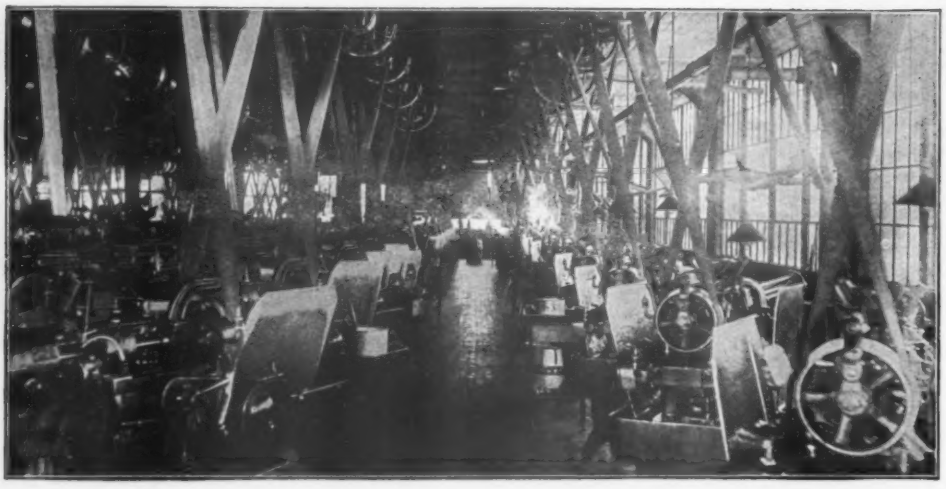

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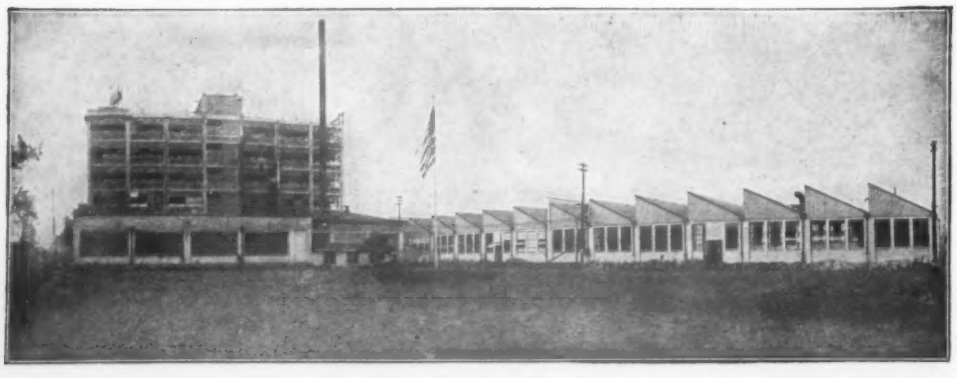

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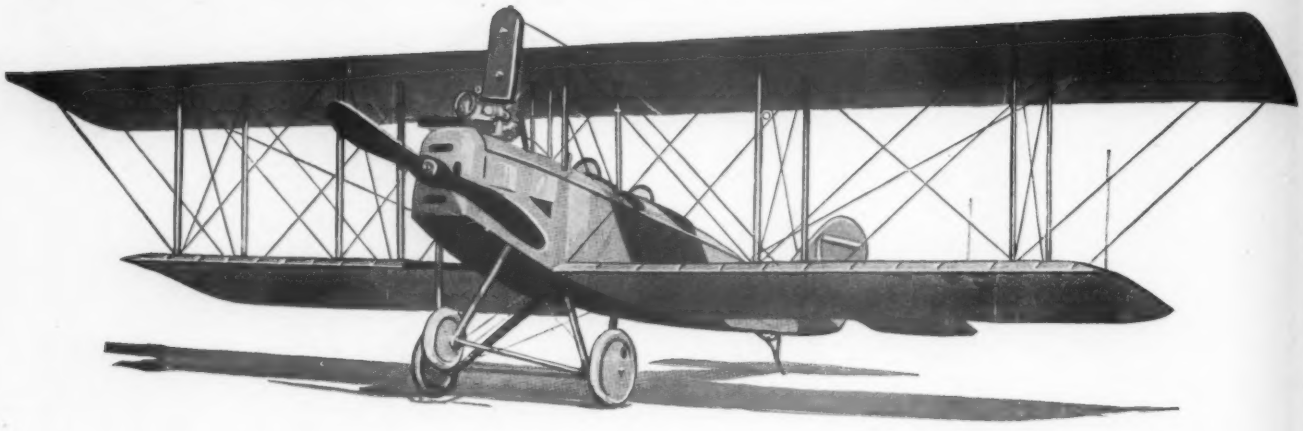

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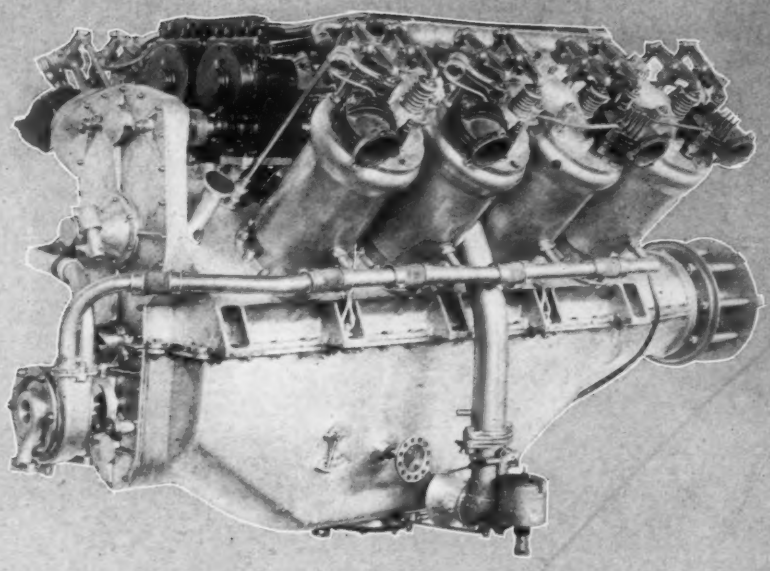

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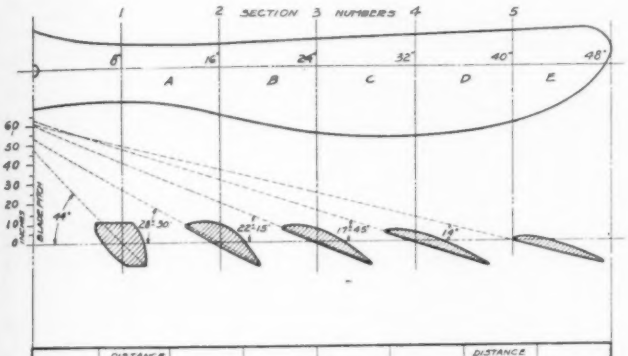
Vol. III | December 1, 1917 | No. 9

Airscrew Analysis

By A. F. Zahm

Introduction

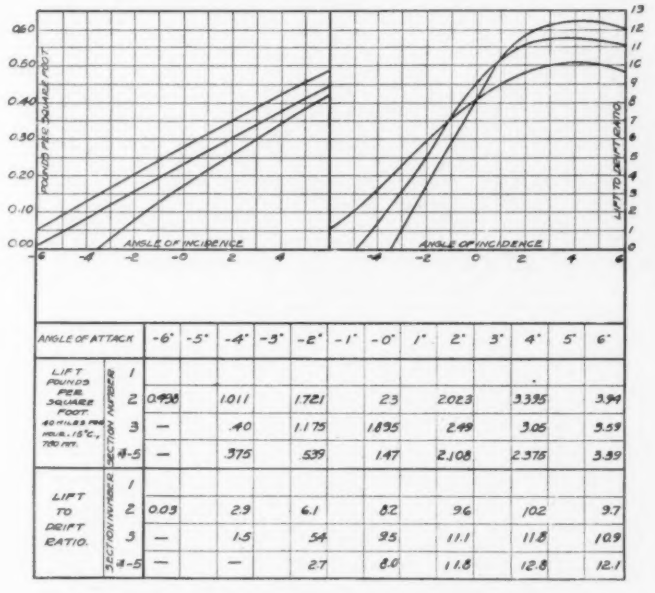
Scope.—In a mathematical estimate of the merits of an airscrew it is customary to make, (1) an aerodynamic analysis; (2) a stress analysis; the first to determine the performance, the second the structural safety.



SECTION.	DISTANCE OF SECTION FROM PROPELLER AXIS FEET.	LENGTH OF SECTION CHORD IN FEET.	SECTION AERA SQUARE INCHES	SECTION MODULUS INCHES	SEGMENT	DISTANCE OF CENTER OF GRAVITY OF SEGMENT FROM PROPELLER AXIS FEET.	MASS OF SEGMENT POUNDS.
1	0667		10.89	360	A	1.000	1251
2	1333	0554	6.90	1101	B	1667	09310
3	2000	0663	6.34	.745	C	2337	08199
4	2667	0701	5.32	.520	D	3000	06673
5	3333	0622	4.17	.385	E	3667	04474

REMARK.—SPECIFIC GRAVITY OF PROPELLER WOOD, 487; TENSILE STRENGTH 9000 POUNDS PER SQUARE INCH.

FIG 1.—PROPELLER BLADE DIMENSIONS



ANGLE OF ATTACK		-6°	-5°	-4°	-3°	-2°	-1°	-0°	1°	2°	3°	4°	5°	6°
LIFT POUNDS PER SQUARE FOOT. 40 MILES PER HOUR. 15°C., 760 MM.	SECTION NUMBER 1													
	2	0498		1011		1721		23		2023		3395		394
	3	—		.40		1175		1895		249		305		359
	4-5	—		375		539		147		2108		2376		339
LIFT TO DRIFT RATIO.	SECTION NUMBER 1													
	2	003		29		61		82		96		102		97
	3	—		15		54		95		111		118		109
	4-5	—		—		27		80		118		128		121

FIG 2.—AERONAUTICAL DATA AND BLADE SECTIONS

Basic Data for Airscrew Analysis.—Most airscrews consist of one or more blades secured to, or integral with, a central hub designed to be carried by a shaft rotating about an axis and moving along it. From hub to tip the blade varies in cross-sectional form, size and incidence. These three elements are usually planned to ensure the greatest efficiency consistent with structural safety and adequate thrust. Basic data for a typical airscrew are given in Figs. 1 and 2.

Aerodynamic Analysis

Velocity and Air Force at Any Blade Section.—Each point of an airscrew blade describes a helical path whose pitch is constant when the speeds of rotation and translation bear a fixed ratio. The path is usually referred not to fixed space but to the general mass of approaching air, since this itself may be in translation. Fig. 3 shows how to find graphically the helix angle A, the incidence i, and resultant velocity $\overline{V}$, at any point of a blade whose peripheral and forward velocities, referred to the general air mass, are given.* Analytically A, i, and V are computed by the formulas:

$$\tan A = V/2\pi rN \quad \ldots\ldots (1)$$

$$V = (V^2 + 4\pi^2 r^2 N^2)^{1/2} \quad \ldots\ldots (2)$$

$$i = B - A$$

where V is the translational, N the rotational speed, r the radial distance of the moving point, and B the blade angle at r.

The unit air force at any section with speed V, may be found in magnitude very approximately by the formula

$$R = K\rho\overline{V}^2 \quad \ldots\ldots (3)$$

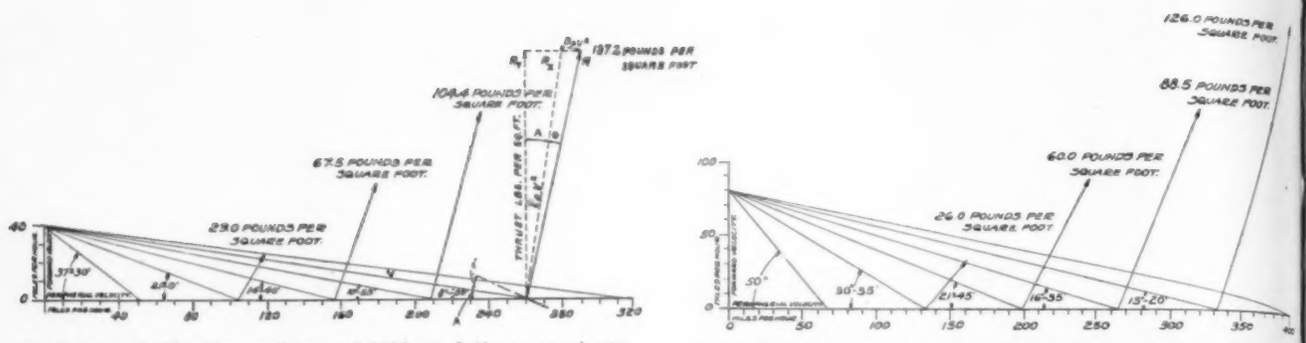
in which ρ is the density, K is the air force per unit surface at unit speed for an aerofoil having the form and incidence of said section and moving in air of unit density. † The direction of R in terms of the incidence is commonly known from aerofoil experiments. Otherwise the unit lift and drift are computed, and thence the resultant force. The unit lift is $L\rho\overline{V}^2$; the drift is $D\rho\overline{V}^2$; their ratio, $D/L = \tan^{-1}G$, gives the "gliding angle," or direction of R referred to the lift.‡ If $\overline{V}$ be in miles per hour the lift and drift per square foot are $.0051L\overline{V}^2$, and $.0051D\overline{V}^2$, respectively.

Thrust and Torque, Thrust Power and Torque Power.—The forward component R_x of the air force in Fig. 3 is the unit thrust; the peripheral component R_z, multiplied by the section radius is the unit torque. Multiplying these units by the blade width gives the thrust and torque per unit length of blade, as tabulated and plotted in Fig. 4; and integrating obviously gives the whole thrust and whole torque for the blade. From these are derived the thrust power and torque power, on multi-

* It is here assumed that the air approaches the screw plane normally with uniform velocity V. A slight correction for this assumption must be made. No perfectly adequate formula is available for this correction. Riach proposes a theoretical formula assuming V normal to the screw plane and increasing in velocity. —Journ. Aeron. Soc. Gt. Brit., March 21, 1917.

† The effect of air viscosity and compressibility are here ignored. No material error thereby ensues. See J. C. Hunsaker, Theory of Similitude of Aerial Propellers; also Edgar Buckingham, Physical Similarity.

‡ L and D are the absolute lift and drift coefficients, or the components of K taken respectively with and across the relative wind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104.4 POUNDS PER SQUARE FOOT.
67.5 POUNDS PER SQUARE FOOT.
29.0 POUNDS PER SQUARE FOOT.
126.0 POUNDS PER SQUARE FOOT.
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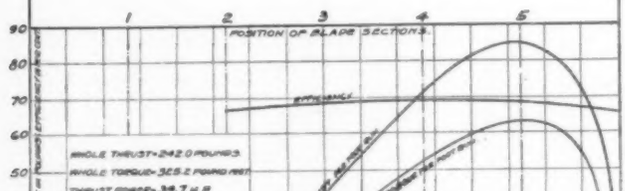
60.0 POUNDS PER SQUARE FOOT.
26.0 POUNDS PER SQUARE FOOT.

For low speed: 40 miles per hour and 1100 revolutions per minute. *For high speed: 80 miles per hour and 1400 revolutions per minute.*

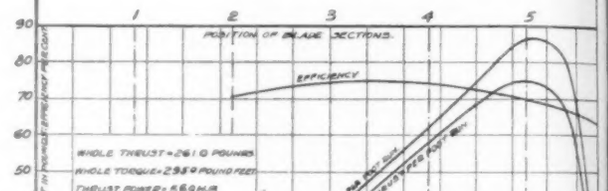
FIG. 3.—VELOCITY AT VARIOUS BLADE SECTIONS AND RESULTANT AIR FORCE PER SQUARE FOOT

BLADE SECTION NUMBER.	ANGLE OF ATTACK.	SPEED ALONG HELICAL PATH MILES PER HOUR.	LIFT IN POUNDS PER SQUARE FOOT.	DRIFT IN POUNDS PER SQUARE FOOT.	THRUST IN POUNDS PER FOOT RUN.	TORQUE IN POUND FEET PER FOOT RUN.	EFFICIENCY AT SECTION.
1	6°-30'	66					
2	7°-30'	112	27.9	3.98	13.50	10.32	66.5
3	7°-35'	162	66.3	6.38	43.50	30.30	68.3
4	6°-50'	213	104.1	8.91	70.50	52.10	68.8
5	5°-10'	264	136.9	10.99	84.60	63.00	68.4


POSITION OF BLADE SECTIONS.
EFFICIENCY.
WHOLE THRUST = 242.0 POUNDS.
WHOLE TORQUE = 325.2 POUND FEET.
THRUST POWER = 34.7 H.P.
TORQUE POWER = 50.8 H.P.
EFFICIENCY = 68.4 PER CENT.
DISTANCE ALONG BLADE IN FEET.

For low speed: 40 miles per hour and 1100 revolutions per minute.

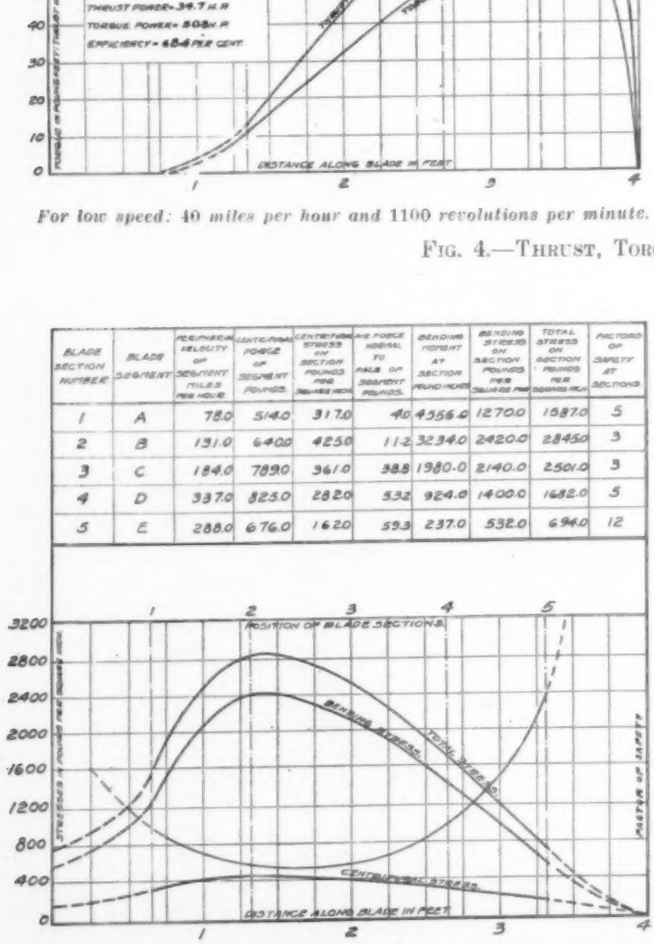
BLADE SECTION NUMBER.	ANGLE OF ATTACK.	SPEED ALONG HELICAL PATH MILES PER HR.	LIFT IN POUNDS PER SQUARE FOOT	DRIFT IN POUNDS PER SQUARE FOOT	THRUST IN POUNDS PER FOOT RUN.	TORQUE IN POUND FEET PER FOOT RUN.	EFFICIENCY AT SECTION.
1	-3°-40'	104				0.00	-00
2	-2°-3'	156	25.5	4.33	10.87	12.32	70.40
3	-0°-40'	215	58.97	5.78	35.3	37.75	74.80
4	1°-10'	277	88.2	8.48	57.6	62.00	74.32
5	0°-40'	342	125.3	12.92	75.5	86.20	70.00


POSITION OF BLADE SECTIONS.
EFFICIENCY.
WHOLE THRUST = 261.0 POUNDS.
WHOLE TORQUE = 295.0 POUND FEET.
THRUST POWER = 56.0 H.P.
TORQUE POWER = 80.0 H.P.
EFFICIENCY = 70.0 PER CENT.
DISTANCE ALONG BLADE IN FEET.

For high speed: 80 miles per hour and 1400 revolutions per minute.

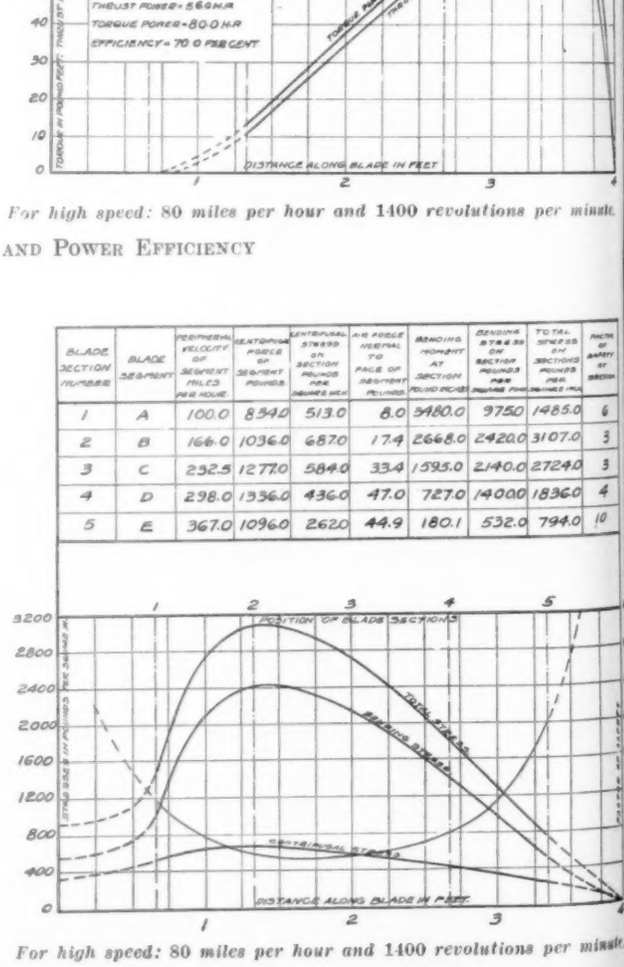
FIG. 4.—THRUST, TORQUE AND POWER EFFICIENCY

BLADE SECTION NUMBER	BLADE SEGMENT	PERIPHERAL VELOCITY OF SEGMENT MILES PER HOUR.	CENTRIFUGAL FORCE OF SEGMENT POUNDS.	CENTRIFUGAL STRESS ON SECTION POUNDS PER SQUARE INCH.	AIR FORCE NORMAL TO FACE OF SEGMENT POUNDS.	BENDING MOMENT AT SECTION POUND INCHES.	BENDING STRESS ON SECTION POUNDS PER SQUARE INCH.	TOTAL STRESS ON SECTION POUNDS PER SQUARE INCH.	FACTOR OF SAFETY AT SECTION.
1	A	78.0	51.40	317.0	40.	4556.0	1270.0	1587.0	5
2	B	131.0	64.00	425.0	11.2	3234.0	2420.0	2845.0	3
3	C	184.0	78.90	361.0	38.8	1980.0	2140.0	2501.0	3
4	D	337.0	82.50	282.0	5.32	924.0	1400.0	1682.0	5
5	E	288.0	67.60	162.0	5.93	237.0	532.0	694.0	12



For low speed: 40 miles per hour and 1100 revolutions per minute.

BLADE SECTION NUMBER	BLADE SEGMENT	PERIPHERAL VELOCITY OF SEGMENT MILES PER HOUR.	CENTRIFUGAL FORCE OF SEGMENT POUNDS.	CENTRIFUGAL STRESS ON SECTION POUNDS PER SQUARE INCH.	AIR FORCE NORMAL TO FACE OF SEGMENT POUNDS.	BENDING MOMENT AT SECTION POUND INCHES.	BENDING STRESS ON SECTION POUNDS PER SQUARE INCH.	TOTAL STRESS ON SECTIONS POUNDS PER SQUARE INCH.	FACTOR OF SAFETY AT SECTION.
1	A	100.0	83.40	513.0	8.0	3480.0	975.0	1485.0	6
2	B	166.0	103.6	687.0	17.4	2668.0	2420.0	3107.0	3
3	C	232.5	127.7	584.0	33.4	1595.0	2140.0	2724.0	3
4	D	298.0	133.6	436.0	47.0	727.0	1400.0	1836.0	4
5	E	367.0	109.6	262.0	44.9	180.1	532.0	794.0	10



For high speed: 80 miles per hour and 1400 revolutions per minute.

FIG. 5.—STRESSES AND FACTOR OF SAFETY

plying respectively by the forward and the rotational speed.*

For use with a propeller computer, to be described presently, the unit thrust is written

$$R_y = .0051\overline{V}.L.V\sec G\cos(A+G) \quad \ldots\ldots\ldots (4)$$

when $.0051\overline{V}$ is called the "velocity factor"; $\overline{V}\sec G\cos(A+G)$ the "thrust factor." Fig. 3 shows that this thrust factor times the lift on an element equals the unit thrust there.

Efficiency.—The efficiency of a propeller, or any part thereof, is the ratio of the useful to the total work in propulsion; or the ratio of the thrust power to the torque power either for the whole or for the part in question.

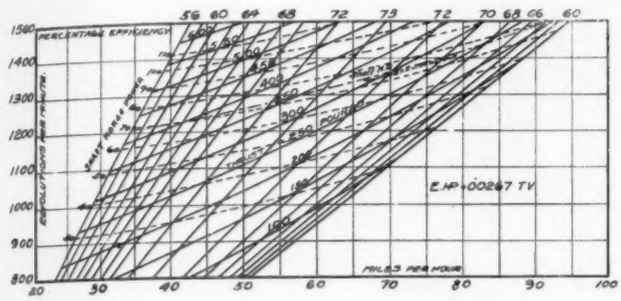


FIG. 6.—PROPELLER THRUST, POWER AND EFFICIENCY FOR VARIOUS SPEEDS

By a well known formula the efficiency of an elementary segment of the blade contained between two cylinders coaxial with the screw is

$$\epsilon = \tan A/\tan(A+G) \quad \ldots\ldots\ldots (5)$$

For proof, Fig. 3 shows that $\overline{V}_y/\overline{V}_x = \tan A : R_y/R_x = 1/\tan(A+G)$

Their product is the efficiency. These statements are true of all blades whatever the form of flow past them, providing $\tan G$, = drift/lift, represent the actual flow. A curve of section efficiency ϵ, derived from this formula is plotted in Fig. 4, together with the corresponding thrust t, and torque q, per foot run.

In practice the curve of running torque q, is derived from the other two by the formula

$$q = ct/\epsilon \quad \ldots\ldots\ldots (6)$$

where c is the ratio V/ω, of the speeds of translation and rotation (in radians per second). From these efficiency and torque curves the efficiency for the entire blade may be found by piecemeal integration.† But the aggregate efficiency is more simply found as the ratio of the whole thrust power to the whole torque power, once these have been computed.

Map of Propeller Characteristics.—When a propeller becomes of permanent interest, a map giving two of its chief characteristics, e.g., its aggregate thrust and efficiency, is made, as in Fig. 6, from which the other three, i.e., the thrust-power, torque and torque power, are readily derived. The map not only tells at a glance the capabilities of the given propeller, but also, through well known laws of comparison, to be given presently, serves to compute quickly the output of others similar to it. The making of this map, which involves several repetitions of the computations already explained for a succession of speeds, is laborious by the usual method, as here indicated, but easy and brief by the use of a suitable instrument.

Propeller Computer.—Fig. 7 shows a kind of slide rule by which the thrust, efficiency, etc.—also various incidental properties of a propeller blade—can be quickly derived. A transparent sliding radial arm, having a central "velocity line" graduated to a linear velocity scale, is pivoted at one corner of a cross-section sheet whose ordinates and abscissae are respectively the forward and peripheral speeds of the blade at various radial distances.

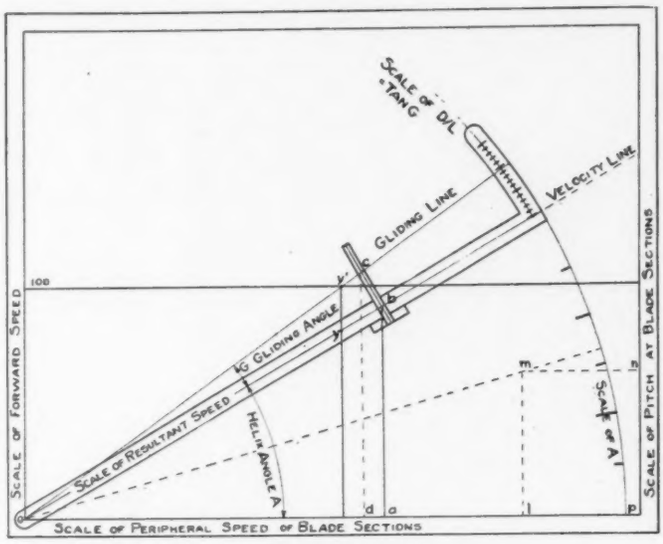


FIG. 7.—PROPELLER COMPUTER

Since $oa = 2\pi rN$, $ab = v$, $\therefore ob = V = (4\pi^2 r^2 N^2 \times v^2)^{\frac{1}{2}}$, called "path velocity."

Since section efficiency $e = \tan A/\tan(A \times G = y/y'$, $\therefore e = y$, if y' be chosen $= 100$.

Since $od = oc \times \cos(A+G)$, and $oc = V \sec G$, $\therefore od = V \sec G \cos(A+G)$, called "thrust factor."

If ol = radius of any blade section whole blade angle = mol, then $pn = 2\pi ml$ = pitch at section.

Path velocity ob, section efficiency y, thrust factor od, pitch pn, all read directly; also helix angle A.

If the radial slide is set with its velocity line passing through the "velocity point" b, on the paper, i.e., a point whose coordinates are the component speeds of any blade section, then ob on this line represents that section's helical velocity $\overline{V}$, while its inclination to the X-axis is the helix angle A for the path of each point of that section, and is read in degrees on the graduated arc at the margin of the paper. This angle taken from the known blade angle for the section gives the incidence.

The center line of the radial arm is also graduated to read $.0051\overline{V}$, called the "velocity factor" in equation (4), and used to find the thrust when $\overline{V}$ is in miles per hour.

Now setting the shown "gliding line," or thread, upon the $\tan G$ scale at the number expressing the drift/lift ratio for this incidence, its inclination to the X-axis is the angle $A+G$. Then is read at once the section efficiency ϵ, as the ratio

Section Radius Feet	Chord Length Feet	Blade Angle	Blade Incidence	Blade Curve Number	Lift Coeff.	Drift / Lift	Section Efficiency	Velocity Factor .0051V	Thrust Factor	Thrust per Foot Run
	a		b				c	d		
Given	Given	Given	Found by Subtraction	Given	Given	Given	Read on Instrument	Read on Instrument	Read on Instrument	Product of a, b, c, d.

FIG. 8.—EFFICIENCY AND RUNNING THRUST AT VARIOUS BLADE SECTIONS

*The method of this paragraph is usually attributed to S. Drzewiecki; see his Des Hélices Aériennes, Paris, F. Louis Vivien, 1909.

†If q, ϵ, be the running torque and efficiency at the radial distance r along the blade, the efficiency for the whole blade is $E = \Sigma q\epsilon dr/\Sigma q dr$

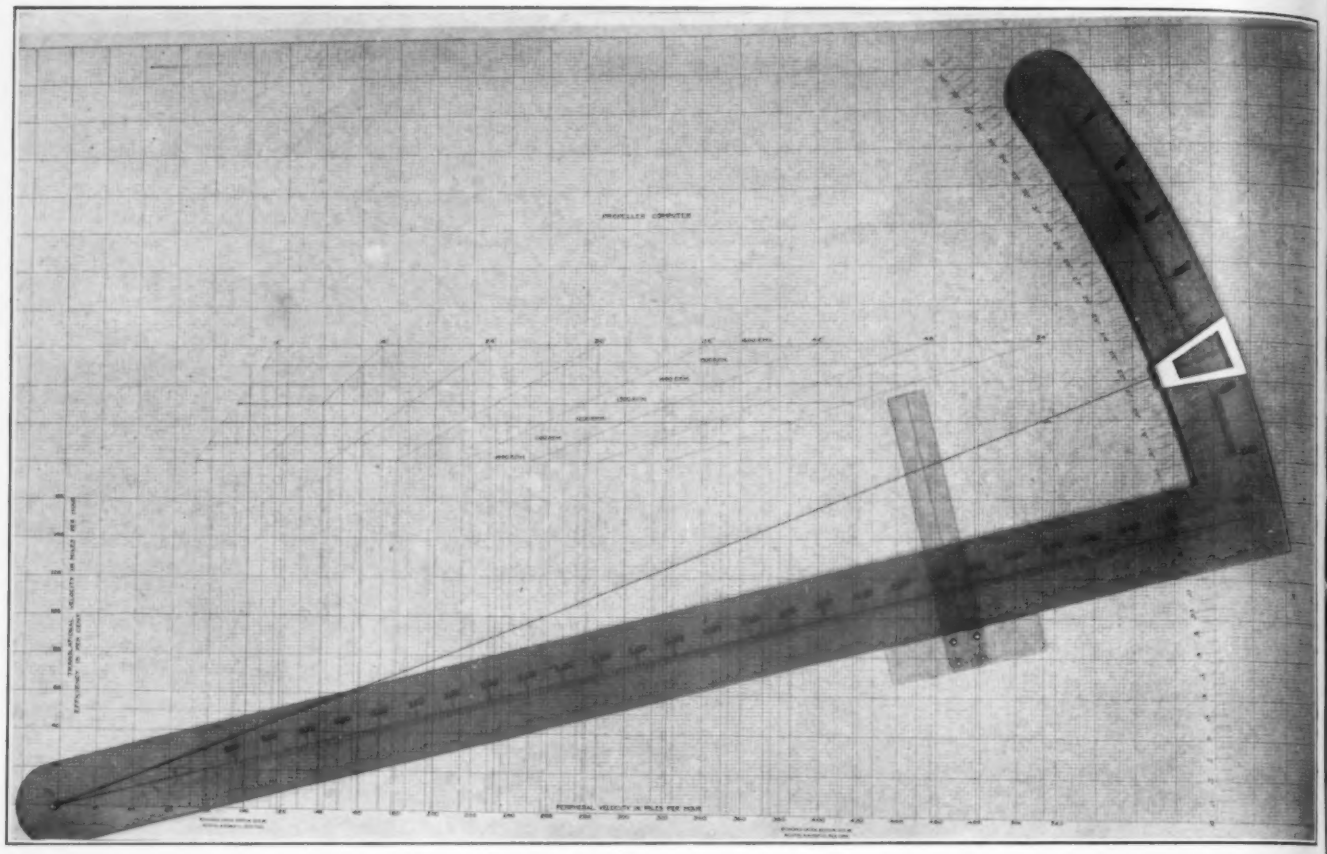


FIG. 9.—PROPELLER COMPUTER

$\tan A/\tan(A + G)$, or the ratio y/y^1 of any two coincident ordinates y, y^1, reaching up respectively to the velocity line and the thread or gliding line. If y^1 be chosen as 100, y is the exact percentage efficiency.

Next the black center line of a transparent T-square is laid over the velocity point b, and squarely across the radial arm, and across the gliding line at the "thrust point" c, whose abscissa is the "thrust factor," $V \sec G \cos(A + G)$.

All the numerical value thus far read from the instrument, together with some given properties and dimensions of the blade sections, are entered in a row, as in Fig. 8. Under them are inserted like readings for other blade sections. Columns a, b, c, and d, are now multiplied together giving the last column. The entire work of taking and entering the readings occupies less than ten minutes.

A practical form of the instrument, as exhibited in Fig. 9, comprises: (1) a sheet of ordinary section paper on a drawing board; (2) a transparent celluloid ruler with one end pivoted at the origin, the other curved to a circular arc; (3) a small celluloid T-square to slide along the straight length of the ruler. Riding on the ruler is a fine thread reaching from the pivot to an aluminum slide which plays freely along the arc. A fuller treatment of the theory and operation of this instrument is given by W. P. Loo in the *Journal of the Franklin Institute* for December, 1917.

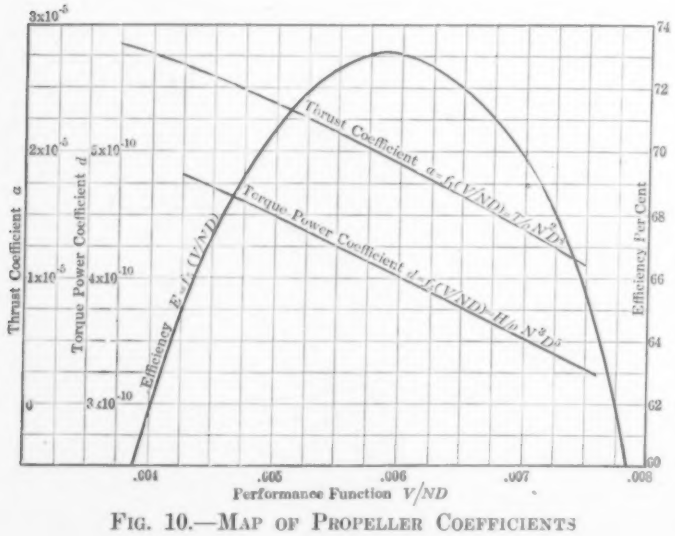


FIG. 10.—MAP OF PROPELLER COEFFICIENTS

Laws of Comparison.—The air force on a small element of a propeller may be written:

$$R = \rho A \overline{V}^2 f^1(i)$$

in which A is the element's area, i its incidence. For an airscrew of fixed shape having a forward velocity V, if i remains constant while the diameter D, and angular speed N, vary,

$$R = \rho N^2 D^4 f(V/ND)$$

since $A \propto D^2$, $V \propto ND$, and i is a function of V/ND. Since the axial and peripheral components of R are similarly expressed, their summation, or the whole thrust and torque may be written

$$\text{Thrust, } T = \rho N^2 D^4 f_1(V/ND) \quad (7)$$
$$\text{Torque, } Q = \rho N^2 D^5 f_2(V/ND) \quad (8)$$

From these follow at once

$$\text{Thrust power} = TV = \rho N^3 D^5 f_3(V/ND) \quad (9)$$
$$\text{Torque power} = 2\pi QN = \rho N^3 D^5 f_4(V/ND) \quad (10)$$
$$\text{Efficiency} = TV/2\pi QN = f_5(V/ND) \quad (11)$$

These five equations furnish useful laws of comparison between geometrically similar propellers. For example if two such screws move at any chosen V/ND in media whose densities are respectively ρ and ρ_1, their thrusts are thus related:

$$T/T_1 = \rho N^2 D^4/\rho_1 N^2_1 D^4_1$$
$$\therefore T = a_1 \rho N^2 D^4,$$
$$\text{where } a_1 = T_1/\rho_1 N^2_1 D^4_1 = f_1(V/ND)$$

If therefore a_1 be observed, or given, for one screw of diameter D_1, the thrust T, of any other, of diameter D, moving with the same V/ND, is found by simple multiplication. Similarly for the torque, etc. Thus it appears that the propeller map here treated furnishes directly the characteristics of a particular airscrew, and, by comparison, those of geometrically similar screws.

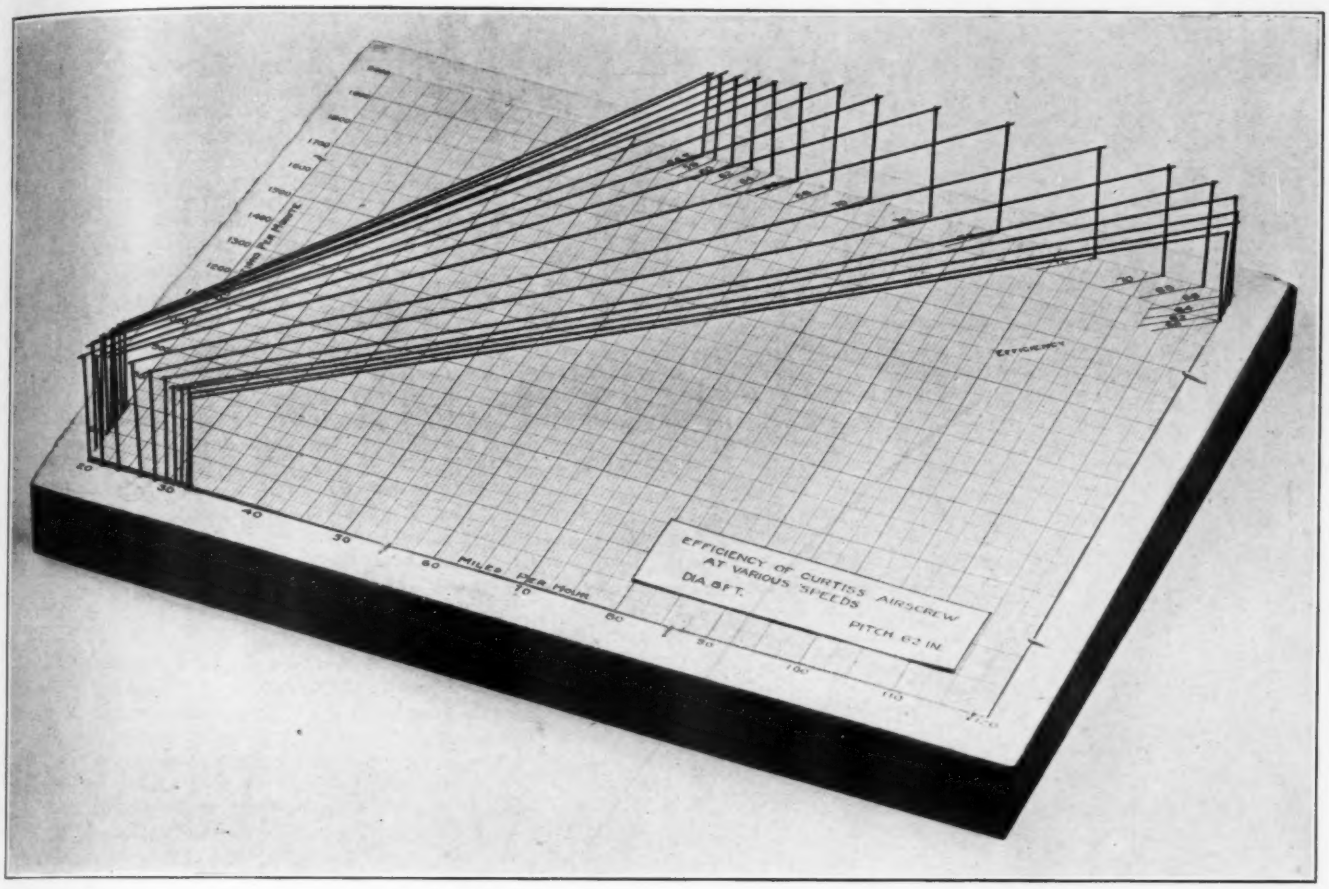


FIG. 11.—EFFICIENCY SURFACE

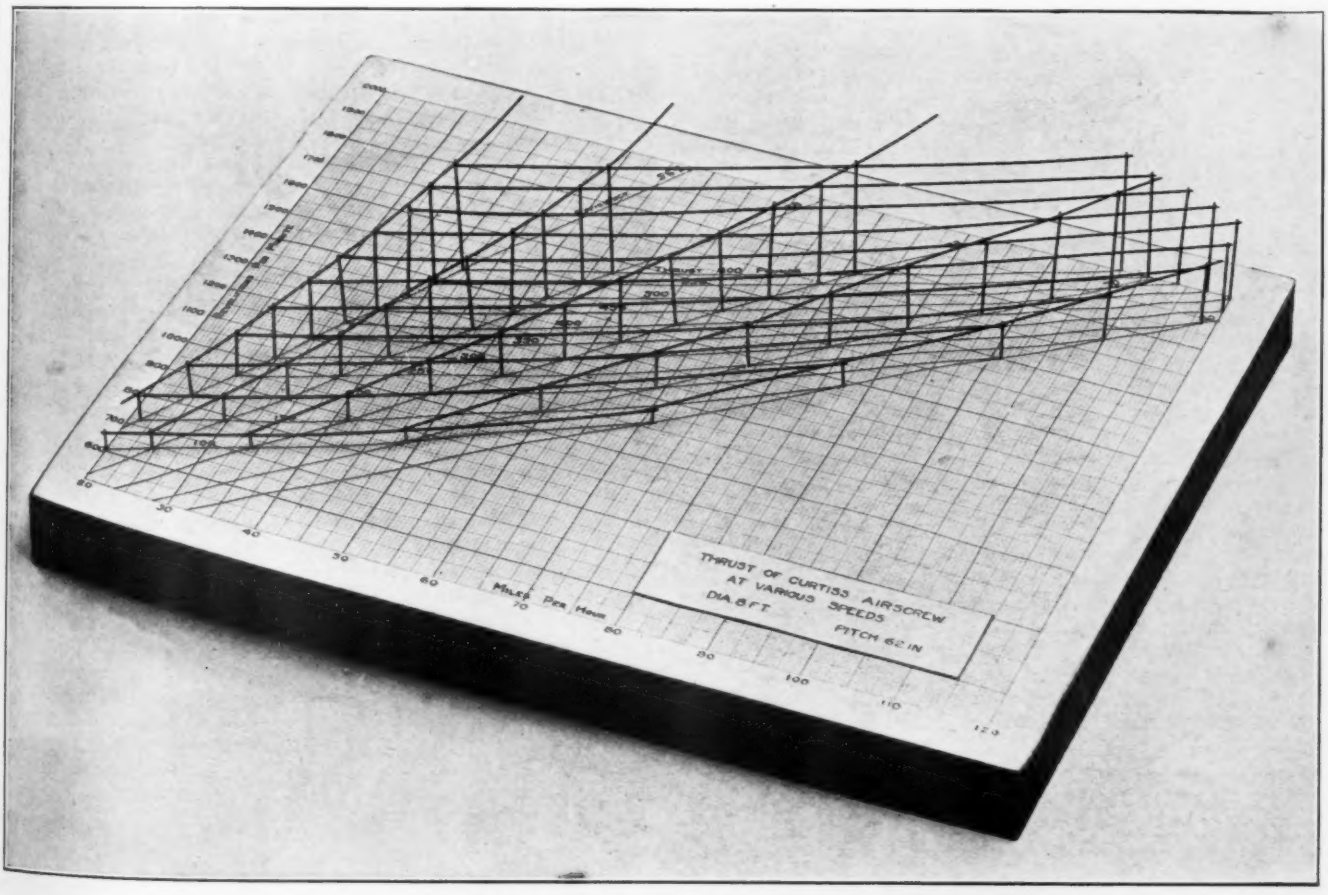
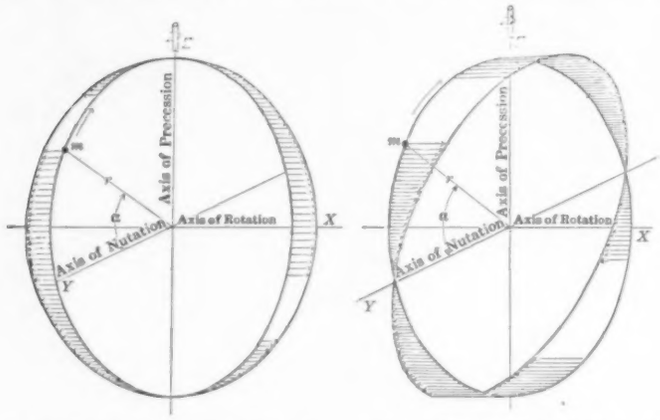


FIG 12.—THRUST SURFACE

Map of Propeller Coefficients.—Assuming V/ND constant, equations 7, 8, 9, 10 and 11, may be written

$$\text{Thrust} = a\rho N^2D^4 \quad (7')$$
$$\text{Torque} = b\rho N^2D^5 \quad (8')$$
$$\text{Thrust power} = c\rho N^3D^5 \quad (9')$$
$$\text{Torque power} = d\rho N^3D^5 \quad (10')$$
$$\text{Efficiency} = E = \text{const} \quad (11')$$

in which a, b, c and d are constants for the given value of V/ND, and are called respectively "thrust coefficient," "torque coefficient," etc. Since as above seen each of these four coefficients is a function of V/ND, it is common practice to plot two of them against V/ND, as in Fig. 10. The corresponding



Perspective representation of gyroscopic velocity of a particle, m.

Perspective representation of gyroscopic acceleration of a particle, m.

FIG. 13.—VELOCITY AND ACCELERATION OF GYROSCOPIC PARTICLE

propeller characteristic is then found for any value of V/ND, by taking the appropriate coefficient from the diagram and substituting in the proper equation above. For example if $a = \rho f_1(V/ND)$, and $d = \rho f_4(V/ND)$, be taken from the diagram and substituted in (7′) and (10′) respectively, they give the thrust and the torque power. From these two characteristics the other three follow as already explained.

Comparison of Maps.—Thus from a map of propeller coefficients one finds by computation values which can be read directly from a map of propeller characteristics. The latter map is more expensive when seldom used; more economical when frequently used for hurried reference. Given either map the other can be produced from it through equations* 7′, 8′, 9′, 10′.

Relief Map of Propeller Characteristics.—The efficiency and thrust values given in Fig. 6 are plotted in relief in Figs. 11 and 12, respectively. The efficiency surface—a species of cylindroid—has for equation $E = f_3(V/N)$, and is generated by a right line rotating about the Z-axis, while oscillating along and perpendicular to it.† The thrust surface has for equation $T = N^2f_1(V/N)$, and is generated by a parabola coaxial with Z and roating about it with varying parameter. Similarly for the torque surface $Q = N^2f_2(V/N)$. The power surfaces are obviously generated by cubic parabolas rotating about Z with altering parameters. Viewed otherwise, the plane V/N = constant contains those generators of the characteristic surfaces and carries them with it while rotating about Z with varying parameter; the parabolas expanding and contracting; the straight line sliding to and fro along Z; and all their projections coinciding with the efficiency line, or trace of the rotating plane on the reference plane $V\ N$.

If the form of any two of these functions, say $f_1(V/N)$, $f_2(V/N)$, were known, the equations to all the five surfaces could be written at once, thus furnishing complete mathematical expressions for the five propeller characteristics. Such functions can be derived analytically when adequate formulae in terms of V and N, are found for L and D, and the velocity and incidence of the air flow at each section of the propeller blade.

The efficiency lines in Fig. 6 are obviously projections of the intersections of the efficiency surface made by planes normal to Z and cutting it at distances from the origin equal to 56, 58, 60, etc., up to 73. Similarly the thrust lines are projections of intersections of the thrust surface made by planes normal to Z and cutting it at distances 100, 150, etc. Similarly for the power curves.

Stress Analysis

Scope.—The stresses in an airerew may be due (a) to constant velocities of rotation and translation, or (b) to variations in one or both.

In *steady rectilinear flight* an airscrew with straight blades—the only form here treated—is subject to two kinds of loading: (1) centrifugal, which begets in the blades purely tensile stress; (2) aerodynamic, which begets bending stress.

To these must be added for *unsteady flight* inertia loads due to three kinds of change of motion: (1) translatory acceleration; (2) rotatory acceleration; (3) precession or nutation. The aerodynamic effects of such velocity changes are slight and not treated here.

(a) *Stresses in Steady Flight.*—For steady rectilinear flight we may first find the centrifugal, then the bending stress, then by superposition find their resultant.

Centrifugal Stress.—The centrifugal force F, at any cross-section of a blade is found by the formula $F = Mv^2/r$, v being the peripheral speed, r the distance, of the center of mass M of the blade segment tending to fly outward from the section in question. Usually this outward segment is mentally cut into smaller segments, whose mass and peripheral speed are first computed then substituted in the given formula, $F = \Sigma mv^2/r$. Dividing F by the section area now gives the average centrifugal stress.

Bending Stresses.—The bending moment M, at any section of a straight radial blade is computed by the formula $M = \Sigma fl$, where f, taken normal to the plane of the neutral surface at the section, is the component of the air force on any small block of the outer segment of the blade, l its distance from the section. Dividing M by the section modulus gives the bending stress in the outer fiber at the section.

Resultant Stress and Safety Factor.—The bending stress is plus or minus; the centrifugal is plus; the maximum is the greatest sum of the positive or tensile stresses. Dividing this sum into the tensile strength of the material gives the factor of safety.

Diagram of Stresses and of Safety Factor.—Fig. 5 portrays graphically the foregoing stresses and factor of safety for all parts of a blade except the tip where they die away, and the root where they are negligible if the hub be properly designed.

Grouping of Data and Analytic Results.—Figs. 1 to 6 present in systematic order the data and analytic results for an entire aerodynamic and stress analysis of a propeller at both high and low speeds of steady flight. The basic data are given in Figs. 1 and 2; the analytic results are given for low speed and for high speed in Figs. 3, 4 and 5. The propeller map, showing the thrust, power and efficiency at various speeds, is reproduced in Fig. 6, and is the aggregate result of a complete aerodynamic analysis for a graded set of speeds of translation and rotation.

(b) *Load Increments Due to Unsteadiness of Flight.*—The added stresses due to unsteadiness of flight are usually smaller than those just treated, but require passing notice.

Translatory Acceleration Loads.—If the screw receives a translatory acceleration j, every particle m opposes this with a force mj, which in practice is negligibly small.

Rotatory Acceleration Loads.—If the screw receives an acceleration $\propto$ about its axis, every particle m opposes this with an inertia force $m\ r\ \omega$, or an axial torque $m\ r^2\ \propto$, where r is the radial distance of m. Hence the axial torque offered by any blade segment against rotatory acceleration is

$$Q = \Sigma m\ r^2\ \propto \quad (12)$$

integrated throughout the segment, and from this value the moment at any blade section, due to the mass of said segment, can be found by elementary statics.

The inertia torque for the whole blade, that is

$$Q = \Sigma (m\ r^2\ \propto) \underset{0}{R} = I \propto, \quad (13)$$

* From these equations it is seen that for ρ, D, V/ND, constant the thrust and torque vary as N^2, the thrust power and torque power vary as N^3, and the efficiency is a constant function of V/N. Hence if these five characteristics be known for one ratio of V/N they are determinate for all values of V, N, having that ratio. Thus all the curves of thrust shown in Fig. 6 are derived from a single one by the relation $T \propto N^2$. Similarly for the curves of torque, thrust power and torque power. The efficiency graphs are obviously all straight lines through the origin of V and N.

† The Z-axis is here assumed normal to the paper and co-ordinate with the V and N axes.

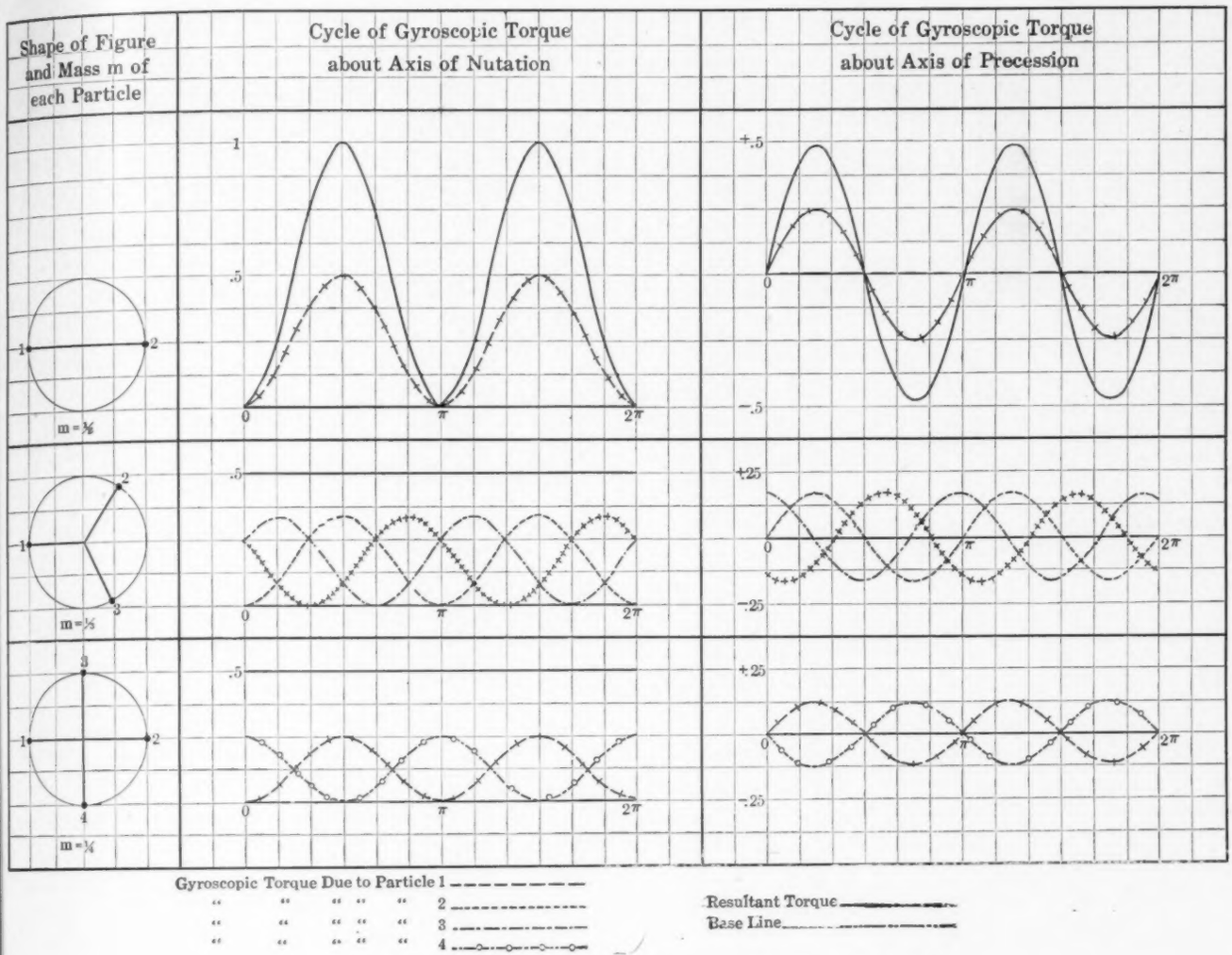

Shape of Figure and Mass m of each Particle
Cycle of Gyroscopic Torque about Axis of Nutation
Cycle of Gyroscopic Torque about Axis of Precession
m=⅛
m=⅛
m=¼
Gyroscopic Torque Due to Particle 1
" " " " " 2
" " " " " 3
" " " " " 4
Resultant Torque
Base Line

FIG. 14.—GYROSCOPIC TORQUE FOR SYMMETRIC PARTICLE GROUPS

where I is the axial moment of inertia, equals the engine torque less the air resistance to rotation. If the screw runs at full speed, first at no throttle, then at full throttle, the opposing blade torque changes from a small negative to full positive value.

*Gyroscopic Loads.**—To express the gyroscopic resistance to pitching and yawing, assume fixed centroidal axes X, Y and Z, through the airscrew parallel to the conventional axes of the airplane, X being the longitudinal axis of the latter; and let ω and Ω, be the angular speeds of rotation and of yaw without pitching. Then any particle m at xyz has parallel to X the linear speed $y\ \Omega$, and the linear acceleration $z\ \omega\ \Omega$, as shown graphically in Fig. 13. Multiplying this acceleration by m gives the force

$$f = mz\,\omega\Omega \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

which varies at quadrant intervals through the values o, m, $r\ \omega\ \Omega$, o, and $-m\ r\ \omega\ \Omega$. This force exerts about Y and Z respectively the torques

$$q_y = mz^2\omega\Omega \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$
$$q_z = -\,myz\omega\Omega \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

which also vary cyclically, as illustrated in Fig. 14, and, together with their resultant, in Fig. 15. Similar effects ensue from pitching without yaw.

The above expressions and the figures illustrating them, show that for yaw without pitch the gyroscopic force on m is always parallel to X, and reverses twice each revolution; that its torque about Y is always positive and fluctuates from zero to a maximum, $m\ r^2\ \omega\ \Omega$, twice each revolution; that its torque about Z oscillates from $m\ r^2\ \omega\ \Omega/2$ to $-\ m\ r\ \omega\ \Omega/2$ twice each revolution; that the resultant torque is a maximum, $m\ r^2\ \omega\ \Omega$, when the particle is crossing the XZ plane. Similar conclusions are obvious for pitch without yaw.

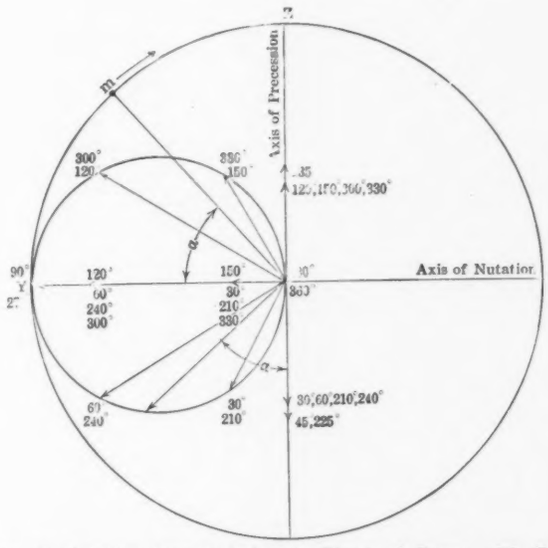

Axis of Precession
Axis of Nutation
Axis of Rotation Perpendicular to Plane of Paper with Positive Direction Upward. Component Torques Represented by Arrows on the Axes. Resultant Torques Represented by the Oblique Arrows.

FIG. 15.—VECTOR TORQUE DIAGRAM FOR A GYROSCOPIC PARTICLE

The entire gyroscopic force on any blade segment is parallel to X, and, when at its maximum value, is very closely

$$F = \Sigma\, mr\omega\Omega\dagger = M\bar{r}\omega\Omega \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

in which M is the mass of the segment, $\bar{r}$ the radial distance of its centroid. This force is at a distance $r_1 = r^2_2/\bar{r}$ from X,

* For a fuller treatment see the writer's "Periodic Stresses in Gyroscopic Bodies with Application to Airscrews," Report of National Advisory Committee for Aeronautics, 1917.

† Owing to the width and thickness of the blade this expression is in slight error less than one part in 5000 for ordinary blades.

where r_s is the radius of inertia of the segment referred to X.

The maximum gyroscopic torque about Y for yawing without pitch is, for any blade segment, $\Sigma\ m\ z^2\ \omega\ \Omega$, integrated throughout the segment; and for a whole screw is

$$Q = I\ \omega\Omega \qquad (18)$$

in which I is the moment of inertia referred to X of the entire screw. The gyroscopic torque of the whole screw or any segment is found for any position α, Fig. 13, by multiplying the maximum by $\sin^2 \alpha$.

Since the entire gyroscopic force on a blade fluctuates like that of a particle, the moment about Y ranges from zero to $I\ \omega\ \Omega$, about Z from $I\ \omega\ \Omega/2$ to $-I\ \omega\ \Omega/2$, twice each revolution. The equivalent gyroscopic stress may therefore be computed as for a repetitive load ranging many times per second from zero to $I\ \omega\ \Omega$.

The 450 Horsepower Friedrichshafen Bomber*

By Jean Lagorgette

The Friedrichshafen Aircraft Works (Flugzeugbau Friedrichshafen, Gesellschaft m.b.H.), which has long specialized in the construction of seaplanes equipped with one and two engines, is now manufacturing a twin-engined bombing airplane, several samples of which have recently been captured on the French front near Verdun and in Macedonia.

This new German bomber possesses substantially the same features as that produced by the Gotha Wagon Works, and might, in fact, be termed a small Gotha. On the other hand, the Friedrichshafen bomber has a great resemblance to the twin-engined seaplane of the same concern, the chief difference consisting in the sweepback of the wings, which is a reversion to earlier German practice.

The Friedrichshafen bomber has an upper span of 20.30 m. and a lower span of 18.85 m., giving an overhang of only 0.72 m. at the wing tips. The wings are slightly tapering in width from the body toward the tips, the chord measuring, respectively, 2.30 m. and 1.80 m. The interplane gap is 1.95 near the body and increases slightly at the tips. The surface area of the wings is 70 sq. m. The overall length of the machine is 11 m.; the overall height, measured from the ground to the upper edge of the rudder, is 4.10 m.

The wings have a slight transverse dihedral, except at the center section, which is rectilinear, and embody a slight backsweep and decalage, the upper plane being offset forward. The trailing edge of the planes is deeply cut out in order to afford clearance to the airscrews.

The wing spars consist of steel tubes in the center section, beyond which they are built up of laminated wood. In accordance with current German practice, the front spar is located very close to the leading edge, at about 0.40 m. from the latter, while the rear spar is situated rather far from the trailing edge, the spars being spaced at about 1 m. from one another. Contrary to what is found in the Gotha, the wing ribs are parallel to the longitudinal axis of the machine.

On the outer side of each engine the wings are braced by two pairs of interplane struts, which are inclined outward; the inner pairs are slightly more inclined than the outer pairs, thus giving the top plane a sharper transverse V than to the lower plane. The overhang of the top plane is, furthermore, braced by stay wires to the lower base of the outer struts.

The wings are painted green and brownish red on the upper surface, and light blue on the lower surface.

The ailerons have an irregular shape and are balanced at the wing tips; they are built up of steel tubing. The surface area of each aileron is 2.30 sq. m.

The elevator has an overall span of 3.95 m. and is 3.65 m. long. The rudder is 1.93 m. high and 0.90 m. wide. Both the elevator and the rudder are built up of steel tubing and are balanced. The fixed tail planes comprise a triangular, vertical fin and a heart-shaped empennage.

Unlike on the Gotha, where the body is a monocoque, the body of the Friedrichshafen bomber is of the well-known four-spar type, with wooden cross members, all suitably stayed. The forward portion, up to the engines, is covered with veneer, the remainder with canvas. The body has an overall height of 1.27 m. and a maximum width of 1.20 m. It can be taken apart at a point flush with the trailing edge of the wings, keys being employed to assemble the two parts. The center section of the planes is fixed to the body by means of a cabane consisting of four vertical steel struts.

In the forward end of the body seats are fitted in tandem fashion for the gunner and the pilot, the former occupying the front seat. The main fuel tank is mounted behind the pilot's seat, and bomb gears are arranged on either side of it. Astern of this is the seat for the second gunner. A passageway runs through the body from the forward to the after seat, thus enabling the crew to change places as the need may occur.

The undercarriage differs considerably from German practice as exemplified in one-engined machines, where it bears only against the body, or in twin-engined machines, where it bears on the wing panels. In the Friedrichshafen bomber the undercarriage bears, through the agency of suitable compression members, on the body as well as on the wing panels. The undercarriage consists essentially of two pairs of vertical struts, each pair bearing on the basis of each engine bed, and carrying twin-wheels on a common axle. Rubber strand shock-absorbers are used. The vertical struts are braced by tubular compression members to the body. No brake is provided on the undercarriage.

The tail skid is pivoted on a vertical post of steel tubing which is braced to the interior of the body. The lower portion of the skid is steel-shod.

The power plant is composed of two water-cooled, 6 cylinder Benz engines, developing from 221 to 226 hp. They are offset 2.10m. from the centerline of the machine, and are mounted each on four V-shaped struts, the apex of which bears, as has been said before, on the vertical struts of the undercarriage. The engines are surrounded by a streamlined bonnet, which mounts in front the radiator and tapers in the rear to a conical cap which is mounted on the airscrews. The diameter of the airscrews is 2.90 m. The fuel tanks are situated in the body, behind the pilot, and have a total capacity of 550 liters. The oil tanks are mounted underneath the radiators.

The control is of the Dep type.

The armament consists of three Parabellum machine guns. One each is mounted on the forward and after seats, on barbette, on a gun ring upon which the gun carriage is made to slide by a lever. The latter permits the locking of the gun in a given position. The third gun is mounted on the floor of the body, on a pivot, and can be fired by the after gun layer through a trap-door which may be operated by a lever. There is consequently no gun tunnel on this machine like the one that was a conspicuous feature of the Gotha.

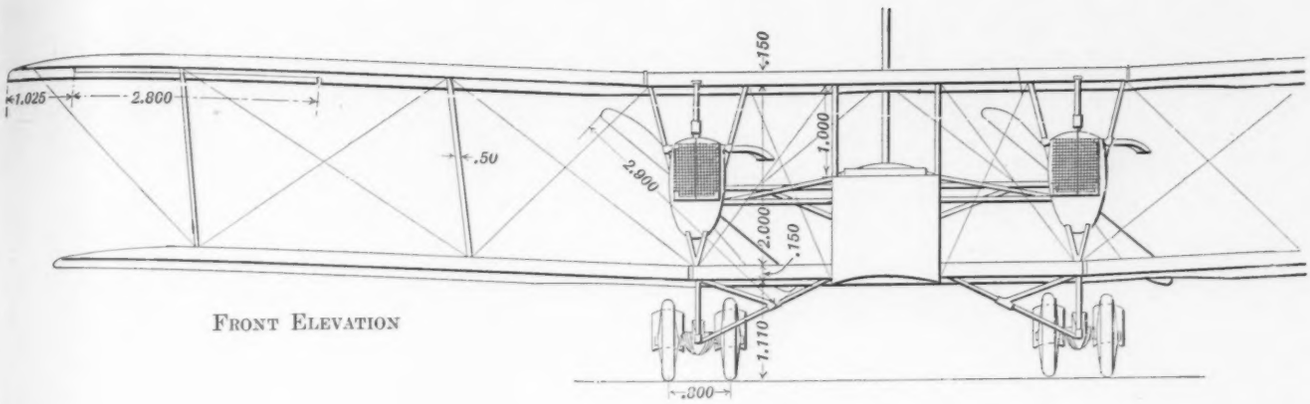
The central bomb gears are of the Gotha type. Six bombs are carried in a vertical row in a self feeding magazine, when one bomb is released another slides automatically into its place. Additional bombs may be carried amidwings, underneath the body, in a spring jaw suspension.

The gross weight of the machine is 2,200 kg., the fuel load 520 kg., and the useful load (crew and ammunition) 432 kg. The total flight weight is, therefore, 3,152 kg., which gives a lift loading of about 45 kg. per sq. in. and a power loading of 7 kg. per horsepower.

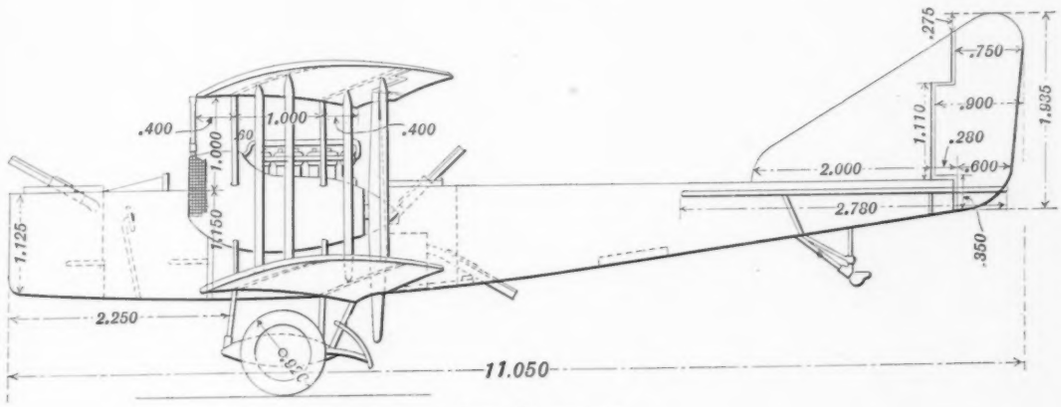
* Excerpt from *L'Aérophile.*

Testing Airplane Fabrics

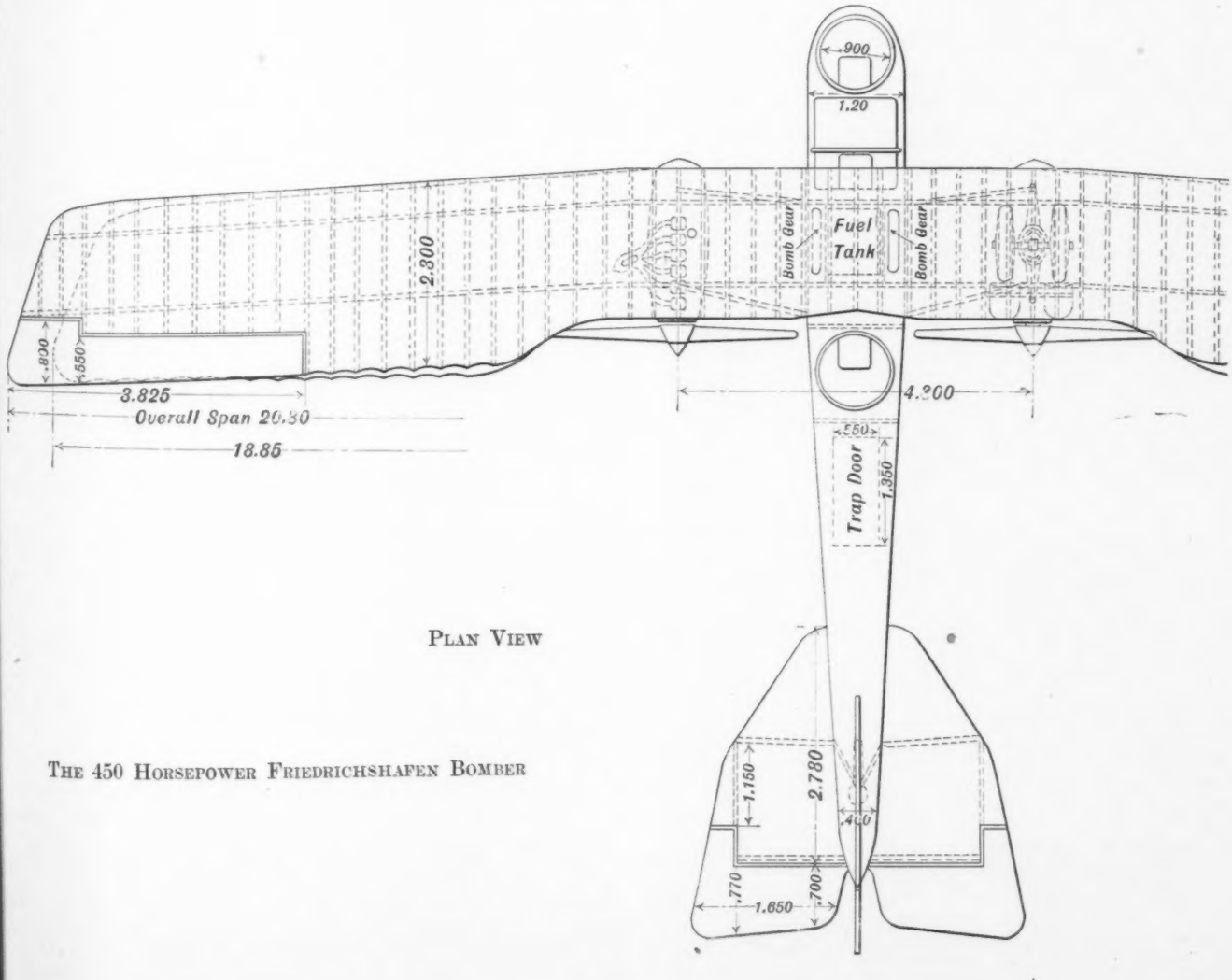
Extensive tests are being made at mills at New Bedford, Mass., to determine the best fabrics for use in airplane wings. Four representatives of the Department of Agriculture have been studying the various raw materials and the manufacture of goods with the object of perfecting an airplane fabric that will be superior to those now in use. The investigators are: William S. Dean, George S. Anderson, C. E. Coburn and R. V. Hellams.



FRONT ELEVATION



SIDE ELEVATION



PLAN VIEW

THE 450 HORSEPOWER FRIEDRICHSHAFEN BOMBER

The 160 HP. Benz and Mercédès Aircraft Engines Compared*

The 160 hp. Benz and the 160 hp. Mercédès engines are, at the present moment, thoroughly representative of current German practice in aircraft engine design, which is emphasized by the fact that nearly all of the enemy airplanes that have been captured by the Allies were found to be equipped with either Benz or Mercédès engines. A detailed analysis and dimensioned comparison of these two engines, which has been authorized by the British naval and military authorities, is, therefore, of timely interest.

Taken as a whole, the Benz and the Mercédès have many

TABLE I.

GENERAL DETAIL.

		160 hp. Benz. Six, vertical	160 hp. Mercédès. Six, vertical
Number and arrangement of cylinders			
Bore	In.	5.12	5.51
Bore	mm.	130.0	140.0
Stroke	In.	7.09	6.30
Stroke	mm.	180.0	160.0
Stroke/bore ratio		1.385 : 1	1.144 : 1
Area of one piston	Sq. in.	20.60	23.84
Total piston area of engine	Sq. in.	123.60	143.04
Swept volume of one cylinder	Cu. in.	146.05	150.20
Total swept volume of engine	Cu. in.	876.30	901.20
Volume of clearance space	Cu. in.	41.65	42.95
Compression ratio. Total volume/clearance volume		4.50 : 1	4.50 : 1
Normal B.H.P.	B.H.P.	160	162.5
Normal speed	R.P.M.	1400	1400
Piston speed	Ft. per min.	1655	1470
Brake mean pressure	Lb. sq. in.	103.00	102.00
Mechanical efficiency (calculated)	Per cent.	87.50	87.90
Indicated mean pressure (calculated)	Lb. sq. in.	117.7	116.0
Fuel consumption per B.H.P. hour (s.g. 0.730)	Lb.	0.520	0.522
Brake thermal efficiency (18,600 B.T.U.'s/lb.)	Per cent.	26.32	26.20
Indicated thermal efficiency	Per cent.	30.10	29.80
Air standard efficiency	Per cent.	45.20	45.20
Relative efficiency	Per cent.	66.60	65.95
Cu. in. of swept volume per B.H.P.	Cu. in.	5.48	5.54
Sq. in. of piston area per B.H.P.	Sq. in.	0.773	0.881
H.P. per cu. ft. of stroke volume	HP.	315.5	312.0
H.P. per sq. ft. of piston area	HP.	186.4	163.5
Direction of rotation of crank and propeller		Anticlock	Anticlock
Normal speed of propeller	R.P.M.	1400	1400
Oil consumption per hour (specific gravity, 0.900)	Lb.	4.93	5.69
Oil consumption per B.H.P. hour	Lb.	0.031	0.035
Number of carbureters	No.	Two	Two
Type of carbureters	Type	Benz	Mercédès
Fuel consumption per hour (specific gravity, 0.730)	Lb.	83.2	84.80
Number and type of magnetos		Two ZH6 Bosch	Two ZU6 Bosch
Firing sequence of engine		1, 5, 3, 6, 2, 4	1, 5, 3, 6, 2, 4
Ignition timing (degrees early, full advance)	Degrees	32	30
Inlet valve opens	Degrees	Top dead center	2 degrees late
Inlet valve closes	Degrees	60 degrees late	35 degrees late
Exhaust valve opens	Degrees	60 degrees early	63 degrees early
Exhaust valve closes	Degrees	18 degrees late	13 degrees late

TABLE Ia.

CALCULATED FRICTION LOSSES. (Lb. per sq. in. of piston area.)

		160 hp. Benz.	160 hp. Mercédès.
Bearings, valve gear and auxiliaries	Lb. sq. in.	2.00	2.00
Fluid Pumping loss	Lb. sq. in.	4.50	4.00
Piston friction	Lb. sq. in.	8.20	8.00
Total Losses	Lb. sq. in.	14.70	14.00
Brake mean pressure	Lb. sq. in.	103.00	102.00
Calculated indicated mean pressure	Lb. sq. in.	117.70	116.00
Calculated mechanical efficiency	Per cent.	87.50	87.90

TABLE II.

GAS VELOCITIES, VALVE AREAS, ETC.

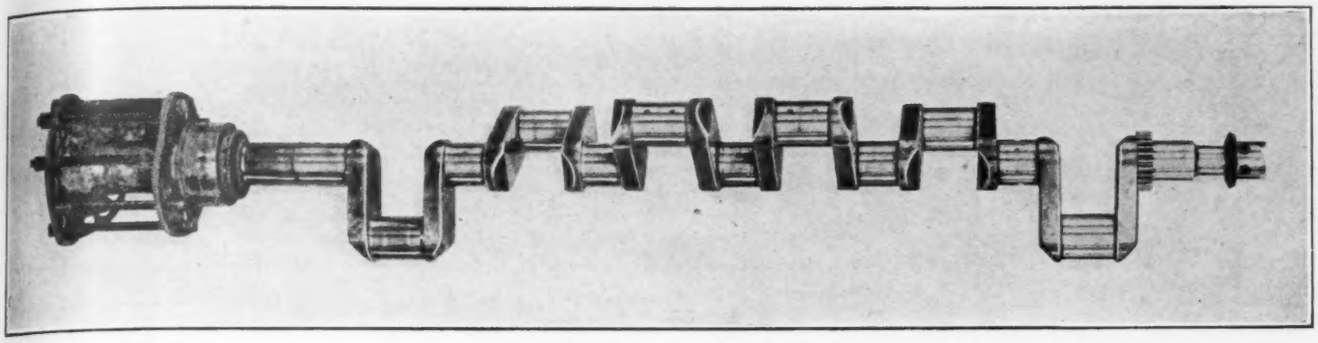
	160 hp. Benz.	160 hp. Mercédès.
GAS VELOCITY (feet per second)—		
Vertical induction pipe	192.0	—
Induction manifold (or branch pipes)	192.0	164.7
Inlet port	123.6	104.5
Inlet valve	172.8	157.7
Exhaust valve	172.8	157.7
Exhaust port	123.6	104.5
Exhaust branch pipe	192.0	164.7
CROSS SECTIONAL AREA (Sq. in.)—		
Vertical induction pipe	2.980	—
Induction manifold (or branch pipes)	2.980	3.546
Inlet port	4.600	5.600
Inlet valve ($\pi\ dh.$)	3.290	3.700
Exhaust valve ($\pi\ dh.$)	3.290	3.700
Exhaust port	4.600	5.600
Exhaust branch pipe	2.980	3.546
DIAMETER (In.)—		
Vertical induction pipe	1.950	—
Induction manifold (or branch pipes)	1.950	2.125
Inlet port	2.420	2.677
Exhaust port	2.420	2.677
Exhaust branch pipes	1.950	2.125

TABLE III.

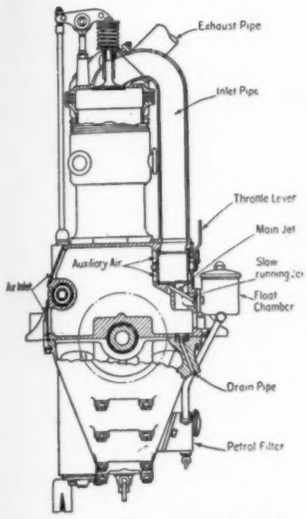
INERTIA FORCES, BEARING LOADS, ETC.

		160 hp. Benz.	160 hp. Mercédès.
Weight of piston, complete with rings and gudgeon pin	Lb.	5.00	6.85
Weight per sq. in. piston area	Lb.	0.2428	0.287
Weight of connecting rod complete	Lb.	5.00	5.00
Total reciprocating weight per cylinder	Lb.	6.80	8.35
Weight per sq. in. piston area	Lb.	0.330	0.350
Length of connecting rod	In.	12.37	11.42
Ratio. Connecting rod/crank throw		3.50 : 1	3.63 : 1
Inertia. Lb. sq. in. piston area. Top center.	Lb. sq. in.	83.60	78.10
Inertia. Lb. sq. in. piston area. Bottom center	Lb. sq. in.	46.40	44.35
Inertia. Lb. sq. in. piston area. Mean	Lb. sq. in.	65.00	61.20
Weight of rotating mass of connecting rod	Lb.	3.20	3.50
Total centrifugal pressure	Lb.	633	611
Centrifugal pressure, lb. sq. in. piston area	Lb. sq. in.	30.70	25.62
Total loading due to inertia and centrifugal pressures	Lb. sq. in.	95.70	86.82
Mean average fluid pressure, including compression	Lb. sq. in.	42.50	42.20
Mean average loading on crank pin bearing, total from all sources in terms of lb. sq. in. piston area	Lb. sq. in.	116.50	108.62
Diameter of crank pin	In.	2.165	2.205
Rubbing velocity	Ft. per sec.	13.22	13.48
Effective projected area of big-end bearing	Sq. in.	4.860	5.400
Ratio. Piston area/projected area of big-end bearing		4.18 : 1	4.37 : 1
Mean average loading on big-end bearing	Lb. sq. in.	487.00	475.00

* Digest from *The Automobile Engineer.*



160 HP. Benz Crankshaft



Ignition System 160 HP. Benz Engine

characteristics in common, and differ from one another only in minor details of design. Both engines bear out plainly the German practice of sacrificing light weight to sturdiness, and, consequently, reliability; both are of the water-cooled, six-cylinder vertical type, with overhead camshaft drive, and possess double ignition and twin carbureters; and, finally, the structural parts of both engines appear to have been designed with the particular view of quantity production.

Details of design which are at variance from one another may be briefly resumed as follows. The overhead camshaft arrangement of the Benz appears as being superior to that of the

TABLE IV.

160 HP. Benz Cylinder Dimensions.

Overall height of bare cylinder from top of base chamber	16.260″	
Depth of spigot at base of cylinder	0.2756″	
Diameter of cylinder over water jacket	6.417″	
Valve centres	2.756″	
Thickness of flange at base of cylinder	0.512″	
Number of holding-down studs per cylinder	Eight.	
Diameter of holding-down studs	0.394″	
Steel water jacket	No. 19 S.W.G. (0.040″)	
Mean thickness of combustion chamber wall	0.2756″	
Bursting stress*	3715	lb. sq. in.
Mean thickness of cylinder barrel	0.1968″	
Tensile stress*	2604	lb. sq. in.

*Note.—Assumed maximum pressure following several consecutive misfire; 400 lb. per sq. in.

TABLE V.

160 HP. Mercédès Cylinder Dimensions.

Overall height of bare cylinder from top of base chamber	15.270″	
Depth of spigot at base of cylinder	0.2756″	
Mean diameter of cylinder over water jacket	6.732″	
Steel water jacket	No. 18 B.W.G. (0.049″)	
Mean thickness of combustion chamber wall	0.1968″	
Bursting stress*	5600	lb. sq. in.
Mean thickness of cylinder barrel	0.1132″	
Tensile stress*	4870	lb. sq. in.

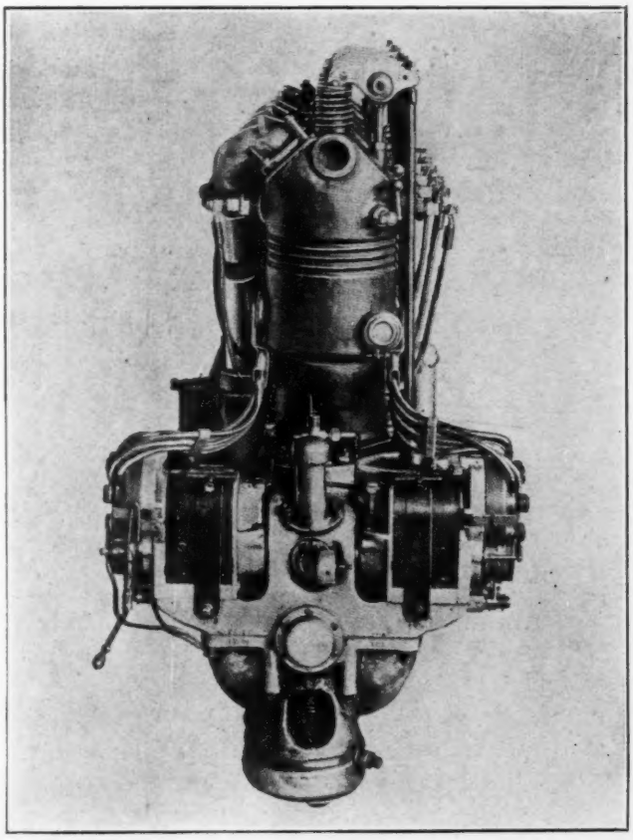
*Note.—Assumed maximum pressure following several consecutive misfires: 400 lb. per sq. in.

TABLE VI.

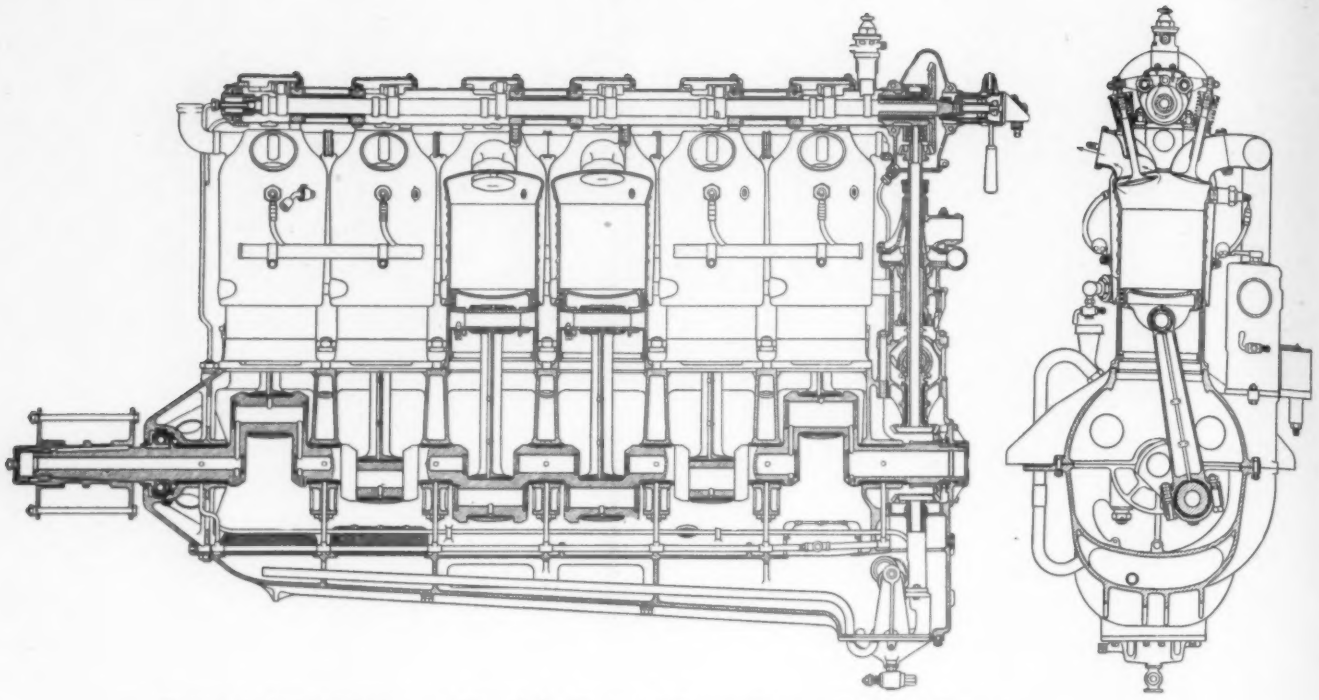
Valve Detail.

		160 hp. Benz.	160 hp. Mercédès.
Outside diameter	In.	2.677	2.834
Port diameter	In.	2.420	2.677
Width of seating	In.	0.0787	0.0787
Radius under valve head	In.	0.3937	0.3149
Lift of valve	In.	0.433	0.440
Diameter of valve stem	In.	0.5512	0.4724
Length of valve guide	In.	2.953	2.756
Overall length of valve	In.	4.921	5.984
Number of springs per valve	No.	One	One
Free length of spring	In.	2.913	3.110
Length of spring in position, no lift	In.	1.968	2.244
Mean diameter of coils	In.	1.535 (parallel)	1.417—1.142 (taper)
Gauge of wire	No. gauge	7-8	8-9
Diameter of wire	In.	0.168	0.1575
Ratio. Length of spring/lift of valve		4.55:1	5.10:1
Weight of valve, complete with spring, cap, etc.	Lb.	0.9926	1.140
Weight of spring, bare	Lb.	0.2405	0.230

The inlet and exhaust valves are interchangeable.



End View of 160 HP. Benz Engine



General Arrangement of Mercédès Engine 140 mm. Bore x 160 mm. Stroke

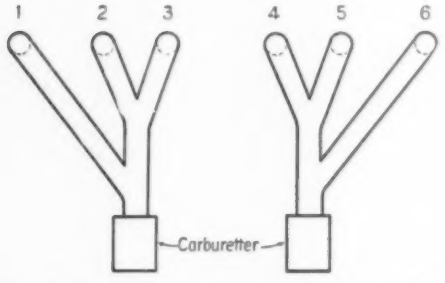


Diagram of Induction Pipe System, 160 HP. Benz Engine

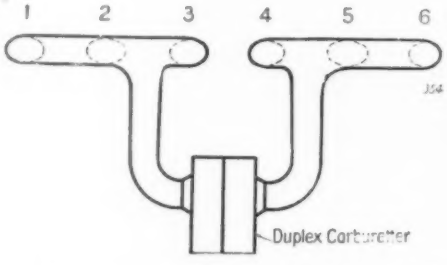
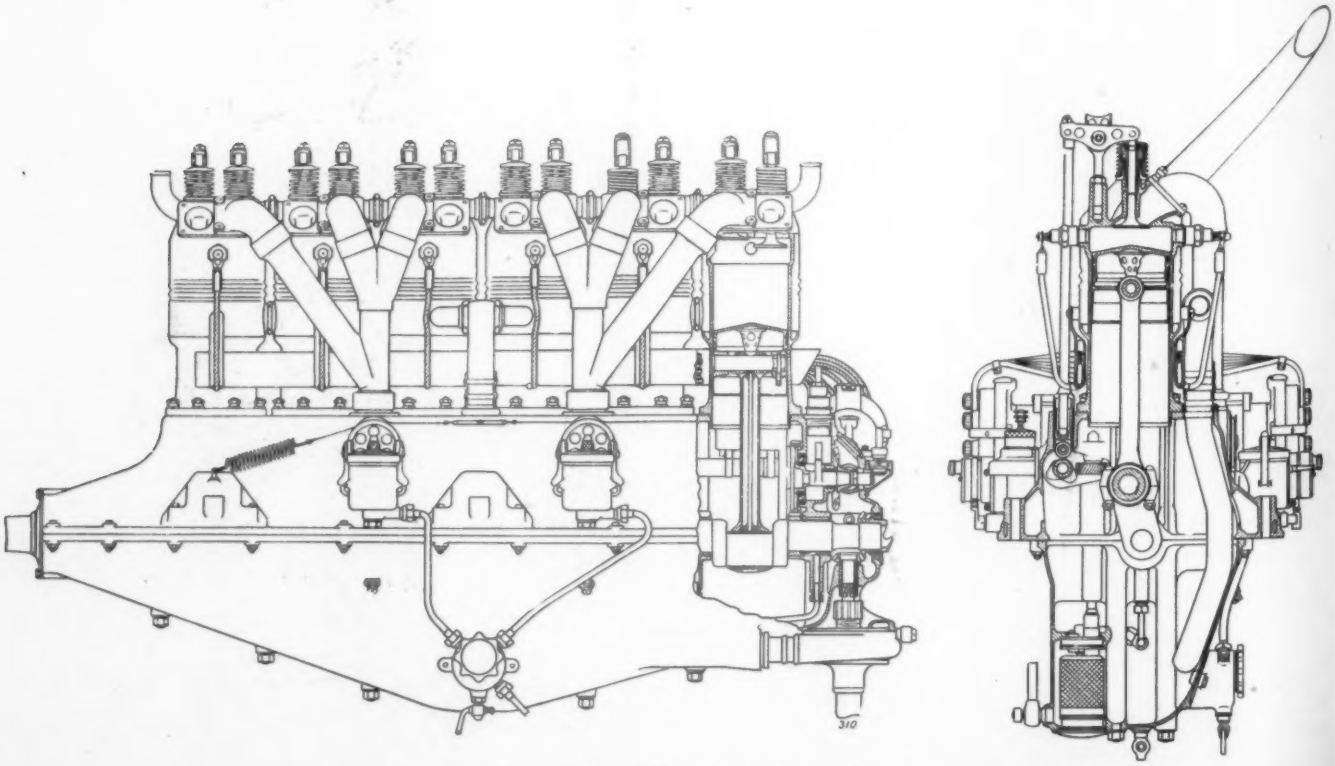
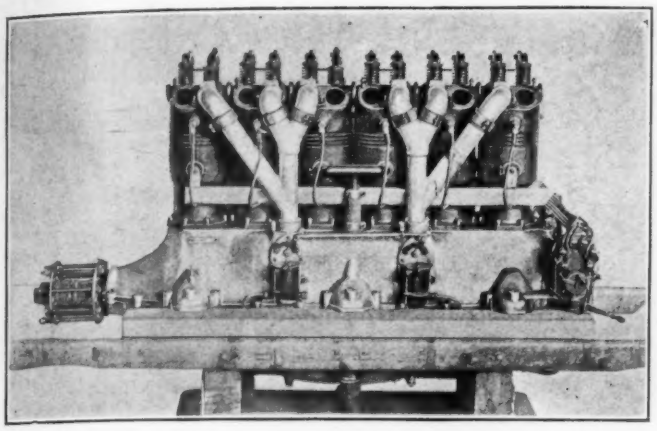


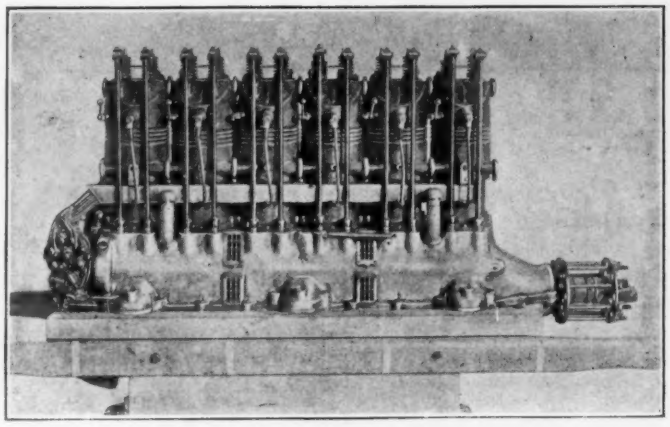
Diagram of Induction Pipe System, 160 HP. Mercédès Engine



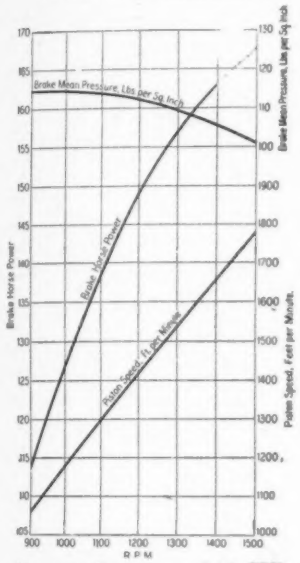
General Arrangement of Benz Engine, 130 mm Bore x 180 mm. Stroke



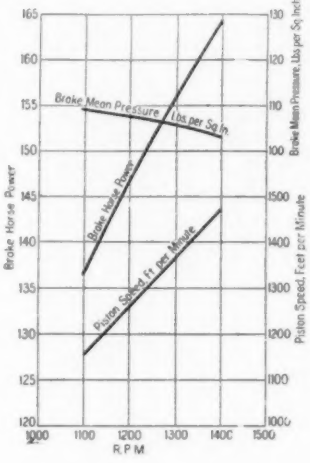
Inlet and Exhaust Side of 160 HP. Benz Engine



Off Side of the 160 HP. Benz Engine



Power Curve of 160 HP. Benz Engine



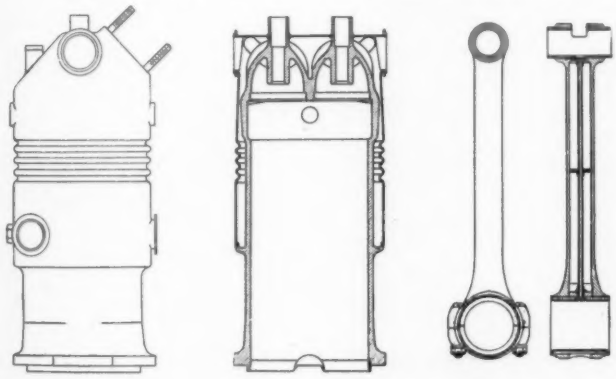
Power Curve of 160 HP. Mercédès Engine

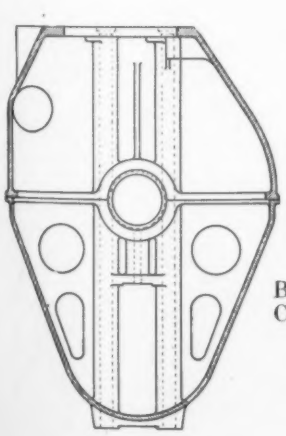
Mercédès, because it may be more easily manufactured, and is also more accessible, although, on the other hand, the Mercédès valve gear is the better arrangement for a high-speed engine. Furthermore, greater rigidity is imparted to the engine unit in the Mercédès design, the cylinders being connected to another by the camshaft housing.

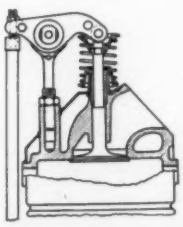
The Benz cylinders are of cast iron with built-up water jackets, the jackets being in both types sheet steel pressings welded to the cylinder heads. The pistons of the Benz are of cast iron, while those of the Mercédès are of the built-up type, comprising a forged steel head, with a cast-iron wall screwed and welded to it.

The water pipe arrangement of the Benz is particularly worthy of note in that it is reduced to a minimum and can easily be taken down.

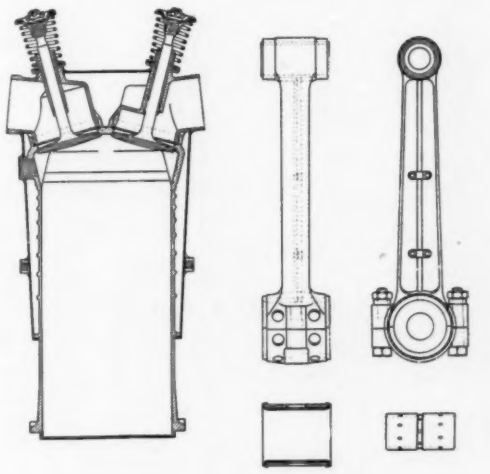
In the accompanying dimensional comparison it has been necessary, owing to the differences in the design of the valve

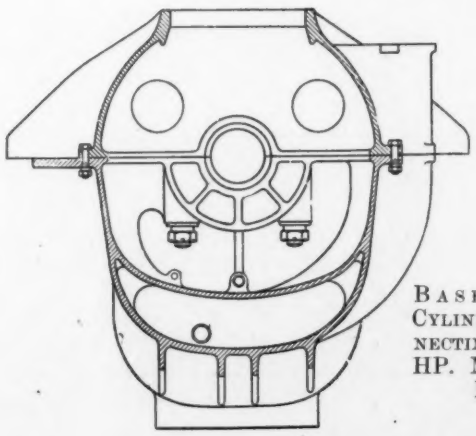






Base Chamber, Cylinder and Connecting Rods, 160 HP. Benz Engine



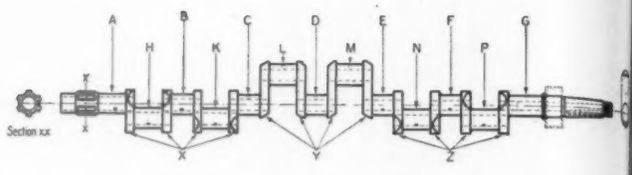


Base Chamber, Cylinder and Connecting Rod, 160 HP. Mercédès Engine

TABLE VII.

CONNECTING ROD AND PISTON.

		160 hp. Benz.	160 hp. Mercédès.
Length between centers	In.	12.37	11.42
Ratio. Connecting rod/crank throw		3.50 : 1	3.63 : 1
Little-end bearing. Type		Phosphor bronze bush fixed in rod	Case-hardened steel bush, floating
Little-end bearing. Diameter	In.	1.180	1.299
Little-end bearing. Length	In.	2.910	2.933
Little-end bearing. Projected area	Sq. in.	3.435	3.810
Ratio. Piston area/projected area of little-end bearing		6.00 : 1	6.26 : 1
Big-end bearing. Type		White metal direct in rod	Bronze shell, lined white metal
Big-end bearing. Diameter	In.	2.165	2.205
Big-end bearing. Length (actual)	In.	2.640	2.874
Big-end bearing. Length (effective)	In.	2.244	2.480
Big-end bearing. Projected area (effective)	Sq. in.	4.860	5.460
Ratio. Piston area/projected area of big-end bearing		4.18 : 1	4.37 : 1
Number of big-end bolts	No.	Four	Two
Full diameter of bolts	In.	0.3937	0.5315
Total cross sectional area bottom of threads	Sq. in.	0.372	0.350
Maximum load due to inertia at 1400 r.p.m.	Lb.	1720	1862
Maximum load due to inertia at 1600 r.p.m.	Lb.	2242	2432
Load due to centrifugal force at 1400 r.p.m.	Lb.	434.5	487
Load due to centrifugal force at 1600 r.p.m.	Lb.	567.5	636
Total load on bolts at 1400 r.p.m.	Lb.	2154.5	2349
Total load on bolts at 1600 r.p.m.	Lb.	2809.5	3068
Stress per sq. in. at 1400 r.p.m.	Lb. sq. in.	5790	6710
Stress per sq. in. at 1600 r.p.m.	Lb. sq. in.	7540	8770



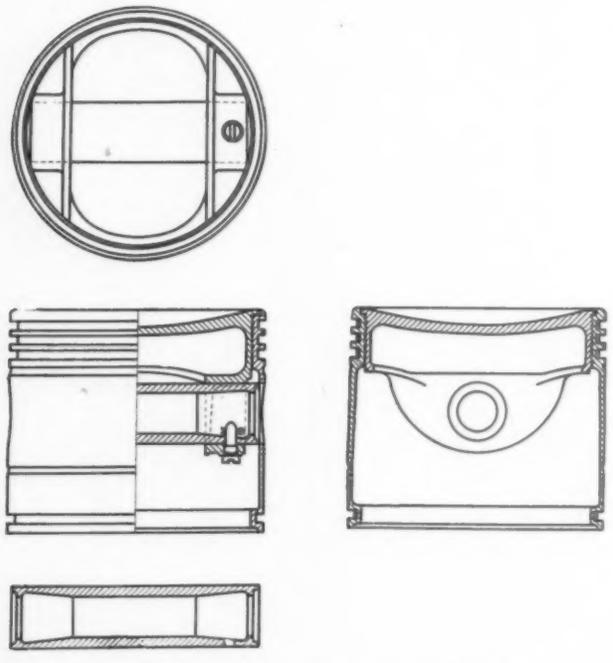
CRANKSHAFT 160 HP. MERCÉDÈS ENGINE

TABLE VIII.

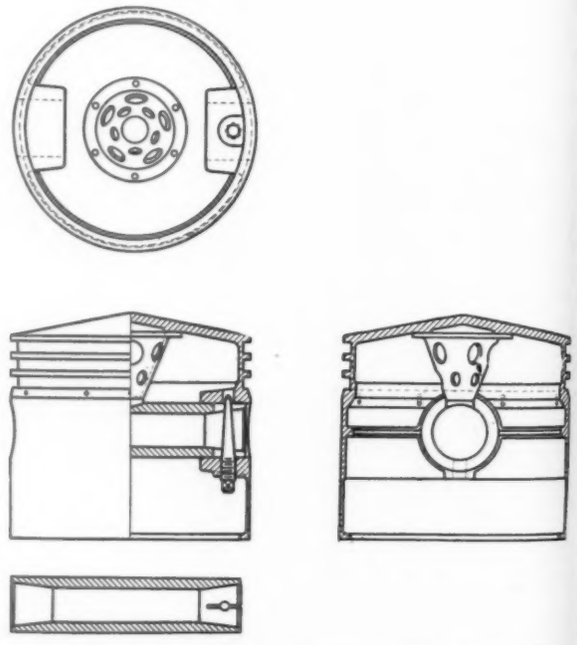
CRANKSHAFT.

		160 hp. Benz.	160 hp. Mercédès.
Length of complete shaft	In.	—	58.48
Cylinder centers	In.	6.690	7.007
Cylinder centers (center pair)	In.	6.690	7.007
Outside diameter of crank pin	In.	2.165	2.205
Inside diameter of crank pin	In.	1.1024	1.26 (mean)*
Length of crank pin	In.	2.716	2.913
Outside diameter of journals	In.	2.165†	2.125
Inside diameter of journals	In.	1.1024	1.16 (mean)*
Number of journal bearings	No.	Seven	Seven
Length of journal bearings. Propeller end	In.	2.756	3.543
Length of journal bearings. Rear end	In.	1.968	2.992
Length of journal bearings. Center	In.	2.2047	2.2835
Length of journal bearings. Intermediate	In.	2.2047	2.2835
Width of crank webs	In.	2.598	2.677 (mean)*
Thickness of crank webs	In.	0.945	0.905 (mean)*
Radius at ends of journals and crank pins	n.	0.197	0.1575
Diameter of drilled oilways in shaft	In.	0.1575	0.1575
Weight of complete shaft	Lb.	72.70	70.00

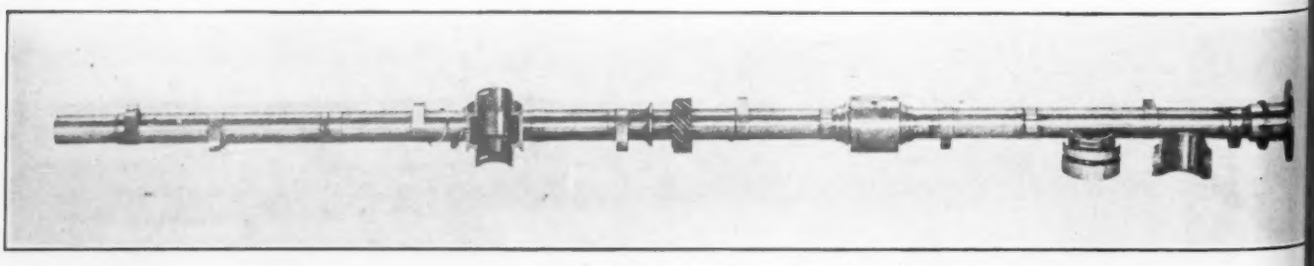
* See Table IX. for dimensions of individual crank pins and journals.
† Except rear journal, which is 1.889" diameter.



160 HP. MERCÉDÈS PISTON AND GUDGEON PIN



160 HP. BENZ PISTON AND GUDGEON PIN



THE BENZ CAMSHAFT

gear, to make some adjustments in weights in order to bring the engines in line for purposes of comparison. The principal alteration consists in including the weight of the camshaft housing, camshaft bearing, etc., of the Mercédès engine in the top half of the base chambers.

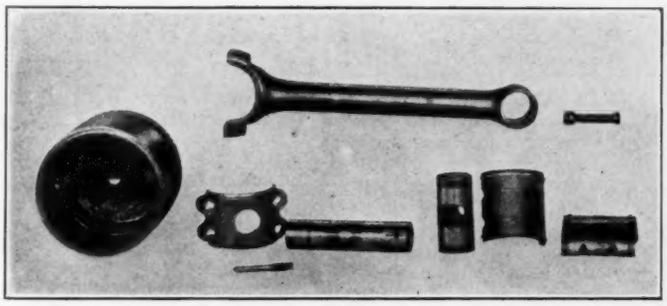
TABLE IX.

APPLIES TO 160 HP. MERCÉDÈS CRANKSHAFT ONLY.

R. = Ratio. External diameter./Internal diameter.

Description.	Dimensions. In.	R.
Outside diameter of all journals	2.126	—
Inside diameter of journal. A	1.535	1.385/1
Inside diameter of journal. B	1.338	1.588/1
Inside diameter of journal. C	1.220	1.742/1
Inside diameter of journal. D	1.102	1.930/1
Inside diameter of journal. E	0.984	2.161/1
Inside diameter of journal. F and G	0.787	2.702/1
Length of journal. A	3.071	—
Length of journal. B, C, and D	2.2835	—
Length of journal. E	2.244	—
Length of journal. F	2.204	—
Length of journal. G	3.543	—
Outside diameter of all crank pins	2.205	—
Inside diameter of crank pin. H	1.456	1.514/1
Inside diameter of crank pin. K	1.338	1.647/1
Inside diameter of crank pin. L	1.220	1.807/1
Inside diameter of crank pin. M, N, and P	1.102	2.00/1
Width of crank webs. X	2.598	—
Width of crank webs. Y	2.677	—
Width of crank webs. Z	2.756	—
Thickness of crank webs. X and Y	0.905	—
Thickness of crank webs. Z*	0.945	—

* Except end web at propeller end, which is 1.023″ thick.



160 HP. BENZ PISTON AND CONNECTING ROD ASSEMBLY

TABLE X.

MISCELLANEOUS WEIGHTS.

	160 hp. Benz. Lb.	160 hp. Mercédès. Lb.
One cylinder complete, less valves	26.00	19.25
Connecting rod complete	5.00	5.00
Piston, complete with rings and gudgeon pin	5.00	6.85
Valve, complete with spring	0.992	1.140
Valve complete, less spring	0.758	0.910
Valve rocker complete	0.436	0.495
Valve tappet complete, less guide	0.211	—
Valve push rod complete	0.535	—
Weight of engine complete, less cooling system, fuel, oil, and tanks	591.50	618.00
Weight per normal ground level B.H.P.	3.70	3.80
Weight of engine complete, including cooling system at 0.65 lb. ground level B.H.P.	695.50	723.60
Weight per normal ground level B.H.P.	4.35	4.45
Weight of engine complete, including cooling system, fuel, oil, and tanks for four hours (fuel and oil allowance at rate of ground level B.H.P., and tanks at rate of 10% of weight of fuel and oil)	1083.30	1121.75
Weight per normal ground level B.H.P.	6.77	6.90

TABLE Xa.

GENERAL ANALYSIS OF WEIGHTS.

Description.	160 hp. Benz. Lb.	160 hp. Benz. Percentage of Total Weight.	160 hp. Mercédès. Lb.	160 hp. Mercédès. Percentage of Total Weight.	Average. Percentage of Total Weight.
Cylinders	168.00	28.40	115.50	18.71	23.555
Base Chamber. Top half	100.00	16.92	118.59	19.21	18.065
Base Chamber. Bottom half	65.75	11.10	73.00	11.82	11.461
Crankshaft complete	72.70	12.28	70.00	11.33	11.806
Propeller hub, complete	12.00	2.06	13.00	2.10	2.080
Propeller thrust race, complete	3.81	0.64	2.56	0.42	0.530
Camshaft, complete	10.50	1.78	10.50	1.63	1.706
Pistons complete including gudgeon pin	30.00	5.07	41.10	6.66	5.866
Connecting rods, complete	30.00	5.07	30.00	4.85	4.960
Valves, complete	11.91	2.01	13.68	2.21	2.110
Valve operating gear between cam and valve stem	14.20	2.40	5.94	0.96	1.680
Induction pipes, complete	8.125	1.37	11.75	1.90	1.635
Carbureters, complete	7.25	1.22	12.73	2.06	1.640
Magnetos, complete	29.00	4.91	30.00	4.86	4.886
Ignition wiring, complete with cable tubes	4.35	0.73	4.00	0.65	0.690
Water pump, complete	4.81	0.81	6.87	1.11	0.960
Water pipes	3.00	0.51	19.00	3.08	1.795
Oil pump, complete	4.55	0.77	12.00	1.94	1.355
Air pump, complete	1.125	0.19	1.50	0.24	0.215
Miscellaneous	10.42	1.76	26.28	4.26	3.005
Total	591.50	100.00	618.00	100.00	100.000

Aeronautical Patents

OCTOBER 9, 1917

1,242,295. To Daniel M. Willard, Bakersfield, Cal., assignor of one-half to Albert J. Mills, Bakersfield, Cal. Flying machine.

1,242,412. To Robert D. Andrews, Brookline, Mass. Flying apparatus.

1,242,540. To Walter R. Fuller, Atlanta, Ga. Airplane.

1,242,553. To Benton H. Jackson, Dayton, Wash. Means for dropping projectiles from air craft.

1,242,766. To James M. Butcher, Chicago, Ill. Airship.

ISSUED OCTOBER 16, 1917

1,243,556—To John J. Reynolds and Arthur Jenkins, Ruleville, Miss. Cargo structure for aircraft.

1,243,557—To John J. Reynolds, Rantoul, Ill. Air pressure-maintenance chamber for aircraft.

ISSUED OCTOBER 23, 1917

1,244,129—To Adolph Ranson, South Charleston, W. Va., assignor of one-half to Stanton Isaac, South Charleston, W. Va. Parachute.

1,244,367—To Prokop Jack Prokop, New York, N. Y. Airship.

ISSUED OCTOBER 30, 1917

1,244,470—To Anders J. Christensen, Hempstead, N. Y. Airplane construction and the like.

ISSUED NOVEMBER 6, 1917

1,245,279—To William H. V. Shrum, Columbus, Ohio. Boomerang.

1,245,389—To Henry W. Schmidt, Edgewater, N. J. Aeronautical apparatus.

1,245,724—To Henry W. Jacobs and Raffe Emerson, Topeka, Kans. Airplane.

1,245,902—To Frank Gretsky, Coal Center, Pa. Airplane motor.

1,246,010—To William Startling Burgess, Marblehead, Mass., assignor to the Curtiss Aeroplane & Motor Corp. Inherently-stable flying boat.

1,246,011—To Glenn H. Curtiss, Hammondsport, N. Y., assignor to the Curtiss Motor Co., Hammondsport, N. Y. Flying boat.

1,246,012—To Glenn H. Curtiss, Hammondsport, N. Y., assignor to The Curtiss Motor Co., Hammondsport, N. Y. Flying boat.

1,246,013—To Glenn H. Curtiss and Henry Kleckler, Hammondsport, N. Y., assignors to the Curtiss Motor Co., Hammondsport, N. Y. Balancing system for aircraft.

1,246,015—To Glenn H. Curtiss, Buffalo, N. Y., assignor to Curtiss Aeroplane & Motor Corp. Airplane.

1,246,016—To Glenn H. Curtiss, Buffalo, N. Y., assignor to Curtiss Aeroplane & Motor Corp. Flying boat.

1,246,018—To Glenn H. Curtiss, Buffalo, N. Y., assignor to the Curtiss Aeroplane & Motor Corp. Draft system for flying boats.

1,246,019—To Glenn H. Curtiss, Buffalo, N. Y., assignor to Curtiss Aeroplane & Motor Corp. Flying-boat hull.

International Aircraft Standards

(Continued from last issue.)

3S25—Specifications for Extra Soft Carbon Steel Sheet

GENERAL.—1. The general specifications, 1G1, shall form, according to their applicability a part of these specifications.

MATERIAL.—2. The material for these sheets shall be chosen from the I. A. S. B. standard steels listed below. The composition shall be stated by the manufacturer or contractor, and is further limited as follows: Carbon, not over 0.15 per cent.

MANUFACTURE.—3. (*a*) The steel shall be manufactured, or at least finished, by the open-hearth, electric-furnace or crucible process.

(*b*) A sufficient discard shall be made from each ingot to secure freedom from piping and undue segregation.

(*c*) Sheets, unless ordered cold rolled, shall be full pickled.

Heat Treatment.—(*d*) Sheets are to be well and uniformly annealed in accordance with good commercial practice. For sheets lighter than 0.065 in. (1.65 mm.), box annealing is preferred. For sheets 0.065 in. (1.65 mm.) and thicker, open annealing is preferred.

WORKMANSHIP AND FINISH.—4. (*a*) The sheets must be commercially flat, clean, smooth, free from seams, laminations, blisters, and other surface defects. They must be uniform in quality, and within the stipulated margins of manufacture.

(*b*) Any sheet may be rejected because of injurious defects or faults in manufacture at any time, notwithstanding that it has previously been accepted by the inspector; it shall be returned to the manufacturer at the latter's expense. This clause shall not be taken to apply to materials fabricated after export.

PHYSICAL PROPERTIES AND TESTS.—5. (*a*) Specimens cut in any direction from the sheets shall have the following properties:

Tensile Test.—(*b*) Minimum tensile strength, 50,000 lb. per sq. in. (35.2 kg.) mm.²); minimum yield point, 30,000 lb. per sq. in. (21.09 kg./mm.²; minimum elongation 25 per cent in 4 in. (101.6 mm.).

Bend Test.—(*c*) Strips cut from sheets shall stand being bent cold through an angle of 180 deg. in any direction to a radius equal to the thickness of the sheet without fracture.

(*d*) Strips 1¼ in. (31.75 mm.) wide cut from sheets and with edges rounded shall stand reverse bending, cold, through an angle of 90 deg. for not less than three complete reversals, without fracture. The test is to be made in a square-nose vise, the edges over which the specimen is bent being rounded to a radius equal to three times the thickness of the sheet.

SELECTION OF TEST SPECIMENS.—6. Three sheets shall be taken from each annealing box to represent the top, middle, and bottom of the stack, or 1 sheet from each 25 when sheets are open annealed. One tensile, one bend, and one reverse bending test shall be made from each sheet selected.

DIMENSIONS AND TOLERANCES.—7. The dimensions and tolerances shall be those given in the table below and in the specifications 3S11. The thickness will be specified in decimals of an inch or millimeters.

DELIVERY, PACKING, AND SHIPPING.—8. (*a*) Sheets shall be cut to the required dimensions and shall be ordered in as narrow widths as can be used.

(*b*) All sheets shall be oiled for protection against corrosion.

(*c*) Sheets 0.065 in. (1.65 mm.) or thinner shall be boxed, the weight of box with contents not to exceed 220 lb. (100 kg.).

(*d*) Sheets thicker than 0.065 in. (1.65 mm.) up to and including 0.125 in. (3.18 mm.), shall be crated, the weight of crate and contents not to exceed 220 lb. (100 kg.).

(*e*) Sheets thicker than 0.125 in (3.18 mm.) may be bundled, the weight of bundle not to exceed 220 lb. (100 kg.).

COMPOSITION OF STANDARD STEELS.

Number.	Carbon.	Manganese.	Phosphorus, maximum.	Sulphur, maximum.
1010	0.05–0.15	0.30–0.60	0.045	0.050

When electric or crucible steel is specified in the order, the maximum allowable percentage of phosphorus and sulphur may, at the option of the purchaser, be limited to 0.03 per cent.

TABLE OF TOLERANCES FOR STANDARD STEEL SHEETS.

Thickness.		Tolerance for sheets 14 inches (35.6 cm.) wide and under.		Tolerance for sheets over 14 inches (35.6 cm.) wide.	
Inches.	*Millimeters.*	*Inches.*	*Millimeters.*	*Inches.*	*Millimeters.*
0–0.020	0.51	+0.001 − .002	+0.03 − .05	±0.002	±0.05
0.021– .030	0.54– .76	+ .002 − .003	+ .05 − .08	± .003	± .08
.031– .040	.79–1.02	± .003	± .08	± .003	± .08
.041– .050	1.05–1.27	± .003	± .08	± .004	± .10
.051– .065	1.30–1.65	± .004	± .10	± .004	± .10
.066– .080	1.68–2.03	± .004	± .10	± .005	± .13
.081– .100	2.06–2.54	± .006	± .15	± .006	± .15
.101– .120	2.57–3.05	± .006	± .15	± .007	± .18
.121– .250	3.08–6.35	± .006	± .15	± .008	± .20

3N11—Specifications for Aluminum Alloy Castings

GENERAL.—1. The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

USE.—2. Two alloys are described.

Alloy 1 is suitable for crank cases and general purposes for which tensile strength is required.

Alloy 2 is suitable for die castings for bearing surfaces and pistons for use at higher temperatures.

MATERIAL.—3. (*a*) These alloys shall have the following compositions:

	Alloy No. 1.	Alloy No. 2.
Specific gravity	2.89	2.95.
Copper	7.0 to 8.5 per cent	9.25 to 10.75 per cent.
Impurities	Not over 1.7 per cent	Not over 1.7 per cent
Aluminum	Balance	Balance.

(*b*) Ingot aluminum of grades Standard No. 1 and Standard No. 2 may be used in making these alloys.

WORKMANSHIP AND FINISH.—4. (*a*) The castings are to be clean, sound, and free from blowholes, misruns, cracks, shrinks, and similar defects.

(*b*) No repairing, plugging, or welding will be allowed unless previous permission in writing has been obtained from the inspector; such permission will only be given when the defects to be repaired are small and do not affect the strength of the casting.

PHYSICAL PROPERTIES AND TESTS.—5. (*a*) The alloys shall have the following minimum physical properties:

Tensile Test.—

	Alloy No. 1, sand cast.	Alloy No. 2, sand or die cast.
Tensile strength	18,000 pounds per square inch (12.65 kg./mm.²).	18,000 pounds per square inch (12.65 kg./mm.²).
Elongation in 2 inches (50.8 mm.)	1.5 per cent	

(*b*) These alloys when poured hot into very thin difficult sections, such as crankcase pans, carburetors, and manifolds, shall not be required to show a greater tensile strength than 14,000 lb. per square inch (9.84 kg./mm.²).

SELECTION OF TEST SPECIMENS.—6. (*a*) At least one sample is to be cast to represent each crank case or other large casting; this is to be attached to the casting; no chills may be applied to the test specimen.

(*b*) The number of test samples for smaller castings is left to the discretion of the inspector, who is to satisfy himself that the quality of the metal used is satisfactory and uniform.

(*c*) The latter samples are to be cast separate, but also in sand and without the use of chills.

DIMENSIONS AND TOLERANCES.—7. (*a*) The castings are to be accurately in accordance with the drawings, and sufficient allowance is to be made to enable them to be machined where required to the finished dimensions without leaving evidence of the cast surface.

(*b*) A tolerance of 3 per cent is allowed in the weight of the individual castings.

3S27—Specifications for One-Half Hard Carbon Steel Sheet

GENERAL.—1. The general specifications, 1G1, shall form, according to their applicability, a part of these specifications.

MATERIAL.—2. The material for these sheets shall be chosen from the I. A. S. B. standard steels listed below. The composition shall be stated by the manufacturer or contractor, and is further limited as follows: Carbon, not over 0.40 per cent; manganese may be from 0.30 to 0.60 per cent.

MANUFACTURE.—3. (*a*) The steel shall be manufactured, or at least finished, by the open-hearth, electric-furnace, or crucible process.

(*b*) A sufficient discard shall be made from each ingot to secure freedom from piping and undue segregation.

(*c*) Sheets, unless ordered cold rolled, shall be full pickled.

Heat Treatment.—(*d*) Sheets are to be well and uniformly annealed, in accordance with good commercial practice. For sheets lighter than 0.065 in (1.65 mm.), box annealing is preferred. For sheets

0.065 in. (1.65 mm.) and thicker, open annealing is preferred.

WORKMANSHIP AND FINISH.—4. (*a*) The sheets must be commercially flat, clean, smooth, free from seams, laminations, blisters, and other surface defects. They must be uniform in quality, and within the stipulated margins of manufacture.

(*b*) Any sheet may be rejected because of injurious defects or faults in manufacture at any time, notwithstanding that it has previously been accepted by the inspector; it shall be returned to the manufacturer at the latter's expense. This clause shall not be taken to apply to materials fabricated after export.

PHYSICAL PROPERTIES AND TESTS.—5. (*a*) Specimens cut in any direction from the sheets shall have the following properties:

Tensile Test.—(*b*) Minimum tensile strength, 75,000 lb. per sq. in. (52.73 kg./mm.²); minimum yield point, 45,000 lb. per sq. in. (31.64 kg./mm.²); minimum elongation, 18 per cent in 4 in. (101.6 mm.).

Bend Test.—(*c*) Strips cut from sheets shall stand being bent cold through an angle of 180 deg. in any direction to a radius equal to the thickness of the sheet without fracture.

(*d*) Strips 1¼ in. (31.75 mm.) wide cut from sheets and with edges rounded shall stand reverse bending, cold, through an angle of 90 deg. for not less than three complete reversals, without fracture. The test is to be made in a square-nose vise, the edges over which the specimen is bent being rounded to a radius equal to three times the thickness of the sheet.

SELECTION OF TEST SPECIMENS.—6. Three sheets shall be taken from each annealing box to represent the top, middle, and bottom of the stack, or 1 sheet from each 25 when sheets are open annealed. One tensile, one bend, and on reverse bending test shall be made from each sheet selected.

DIMENSIONS AND TOLERANCES.—7. The dimensions and tolerances shall be those given in the table below and in the specifications 3S11. The thickness will be specified in decimals of an inch or millimeters.

DELIVERY, PACKING, AND SHIPPING.—8. (*a*) Sheets shall be cut to the required dimensions and shall be ordered in as narrow widths as can be used.

(*b*) All sheets shall be oiled for protection against corrosion.

(*c*) Sheets 0.065 in (1.65 mm.) or thinner, shall be boxed, the weight of box with contents not to exceed 220 lb. (100 kg.)

(*d*) Sheets thicker than 0.065 in. (1.65 mm.), up to and including 0.125 in. (3.18 mm.), shall be crated, the weight of crate and contents not to exceed 220 lb. (100 kg.).

(*e*) Sheets thicker than 0.125 in. (3.18 mm.), may be bundled, the weight of bundle not to exceed 220 lb. (100 kg.).

CHEMICAL COMPOSITION OF STANDARD STEEL.

Number.	Carbon.	Manganese.	Phosphorus, maximum.	Sulphur maximum.
1030	0.25–0.35	0.50–0.80	0.045	0.050
1035	.30– .40	.50– .80	.045	.050

When electric or crucible furnace steel is specified in the order, the maximum allowable percentages of phosphorus and sulphur may, at the option of the purchaser, be limited to 0.03 per cent.

TABLE OF TOLERANCES FOR STANDARD STEEL SHEETS.

Thickness.		Tolerance for sheets 14 inches (35.6 cm.) wide and under.		Tolerance for sheets over 14 inches (35.6 cm.) wide.	
Inches.	*Millimeters.*	*Inches.*	*Millimeters.*	*Inches.*	*Millimeters.*
0–0.020	0.51	+0.001 − .002	+0.03 − .05	±0.002	±0.05
0.021– .030	0.54– .76	+ .002 − .003	+ .05 − .08	± .003	± .08
.031– .040	.79–1.02	± .003	± .08	± .003	± .08
.041– .050	1.05–1.27	± .003	+ .08	± .004	± .10
.051– .065	1.30–1.65	± .004	± .10	± .004	± .10
.066– .080	1.68–2.03	± .004	± .10	± .005	± .13
.081– .100	2.06–2.54	± .006	± .15	± .006	± .15
.101– .120	2.57–3.05	± .006	± .15	± .007	± .18
.121– .250	3.08–6.35	± .006	± .15	± .008	± .20

3S26—Specifications for Soft Carbon Steel Sheet

GENERAL.—1. The general specifications. 1G1, shall form, according to their applicability, a part of these specifications.

MATERIAL.—2. The material for these sheets shall be chosen from the I. A. S. B. standard steels listed below. The composition shall be stated by the manufacturer or contractor, and is further limited as follows: Carbon, not over 0.30 per cent; manganese may be from 0.30 to 0.60 per cent.

MANUFACTURE.—3. (*a*) The steel shall be manufactured, or at least finished, by the open-hearth, electric-furnace, or crucible process.

(*b*) A sufficient discard shall be made from each ingot to secure freedom from piping and undue segregation.

(*c*) Sheets, unless ordered cold rolled, shall be full pickled.

Heat Treatment.—(*d*) Sheets are to be well and uniformly annealed, in accordance with good commercial practice. For sheets lighter than 0.065 in. (1.65 mm.), box annealing is preferred. For sheets 0.065 in. (1.65 mm.) and thicker, open annealing is preferred.

WORKMANSHIP AND FINISH.—4. (*a*) The sheets must be commercially flat, clean, smooth, free from seams, laminations, blisters, and other surface defects. They must be uniform in quality, and within the stipulated margins of manufacture.

(*b*) Any sheet may be rejected because of injurious defects or faults in manufacture at any time, notwithstanding that it has previously been accepted by the inspector; it shall be returned to the manufacturer at the latter's expense. This clause shall not be taken to apply to materials fabricated after export.

PHYSICAL PROPERTIES AND TESTS.—5. (*a*) Specimens cut in any direction from the sheets shall have the following properties:

Tensile Test.—(*b*) Minimum tensile strength, 60,000 lb. per sq. in. (42.18 kg. mm.₂); minimum yield point, 36,000 lb. per sq. in. (25.31 kg. mm.₂); minimum elongation, 22 per cent in 4 in. (101.6 mm.).

Bend Tests.—(*c*) Strips cut from sheets shall stand being bent cold through an angle of 180 deg. in any direction to a radius equal to the thickness of the sheet without fracture.

(*d*) Strips 1¼ in. (31.75 mm.) wide cut from sheets and with edges rounded shall reverse bending, cold, through an angle of 90 deg. for not less than three complete reversals without fracture. The test is to be made in a square-nose vise, the edges over which the specimen is bent being rounded to a radius equal to three times the thickness of the sheet.

SELECTION OF TEST SPECIMENS.—6. Three sheets shall be taken from each annealing box to represent the top, middle, and bottom of the stack, or one sheet from each 25, when sheets are open annealed. One tensile, one bend, and one reverse bending test shall be made from each sheet selected.

DIMENSIONS AND TOLERANCES.—1. (*a*) The dimensions and tolerances shall be those given in the table below and in the specifications 3S11. The thickness will be specified in decimals of an inch or millimeters.

DELIVERY, PACKING, AND SHIPPING.—8. (*a*) Sheets shall be cut to the required dimensions and shall be ordered in as narrow widths as can be used.

(*b*) All sheets shall be oiled for protection against corrosion.

(*c*) Sheets 0.065 in (1.65 mm.) or thinner shall be boxed, the weight of box with contents not to exceed 220 lb. (100 kg.).

(*d*) Sheets thicker than 0.065 in. (1.65 mm.), up to and including 0.125 in. (3.18 mm.), shall be crated, the weight of crate and contents not to exceed 220 lb. (100 kg.).

(*e*) Sheets thicker than 0.125. in (3.18 mm.) may be bundled, the weight of bundle not to exceed 220 lb. (100kg.).

COMPOSITION OF STANDARD STEELS

Number.	Carbon.	Manganese.	Phosphorus, maximum.	Sulphur maximum.
1020	0.15–0.25	0.30–0.60	0.045	0.050
1025	.20– .30	.50– .80	.045	.050

When electric or crucible furnace steel is specified in the order, the maximum allowable percentage of phosphorus and sulphur may, at the option of the purchaser, be limited to 0.03 per cent.

TABLE OF TOLERANCES FOR STANDARD STEEL SHEETS.

Thickness.		Tolerance for sheets 14 inches (35.6 cm.) wide and under.		Tolerance for sheets over 14 inches (35.6 cm.) wide.	
Inches.	*Millimeters.*	*Inches.*	*Millimeters.*	*Inches.*	*Millimeters.*
0–0.020	0.51	+0.001 − .002	+0.03 + .05	±0.002	±0.05
0.021– .030	0.54– .76	+ .002 − .003	+ .05 − .08	± .003	± .08
.031– .040	.79–1.02	± .003	± .08	± .003	± .08
.041– .050	1.05–1.27	± .003	− .08	± .004	± .10
.051– .065	1.30–1.65	± .004	± .10	± .004	± .10
.066– .080	1.68–2.03	± .004	± .10	± .005	± .13
.081– .100	2.06–2.54	± .006	± .15	± .006	± .15
.101– .120	2.57–3.05	± .006	± .15	± .007	± .18
.121– .250	3.08–6.35	± .006	± .15	± .008	± .20

Digest of the Foreign Aeronautical Press

Aeronautics (London), October 24, 1917

The Air Offensive.—With a view to the great air offensive in the spring, the Germans have been content to allow their program of aircraft construction to be announced to the world through a neutral medium. They are about, it appears, to launch forth on construction and design to the uttermost limit of their manufacturing resources. They intend, according to this source of information, to concentrate on the production

POWER-UNIT OF A FRENCH AIRSHIP

Passed by Committee on Public Information
Photo Central News Photo Service

of four main types of machines: the fighting single-seater scout, the two-seater reconnaissance fighter with long radius of action, the long-distance bomber, and the infantry-fighter, or contact patrol airplane.

Of the first type the Germans already possess an abundance; heavily-engined, of excellent flying performance, their fighting scouts and escorts are almost the equal of ours. And that slight degree of superiority which we manage to maintain is due perhaps to the personal ascendency of our our flying men.

In the fighter-reconnaissance airplane we have a clear superiority, provided the authorities exercise clear judgment in their orders now—for our present orders of machines will determine our success six months hence. It should not be forgotten, though only too often it is, that an aerial program involving material production requires months for its elaboration, let alone for its execution. Machines have to be built—which means that designers have to be instructed, materials provided, whole technical staffs trained in their special jobs, and pilots and the remaining personnel trained in their various duties. All of which takes time, even with the best will and the most efficient means in the world. Those who lightly speak of an aerial offensive on a grand scale, of fleets of hundreds of bombing planes, as a rule little realize the enormous amount of preparatory work and the length of time required for the attainment of this object.

In long-distance bombers we should again hold the upper hand, again assuming a modicum of clear thinking on the part of authority. But let this be said: if our offensive in the air is to succeed, we require bombing machines capable of use in daylight raids apart from night-bombers and in day bombers in order to be successful and to be capable of operating far from their base (that is, so as to be able to dispense with escort) have to be exceptionally speedy and possess a high "ceiling."

In the matter of infantry-fighters we are less clear, if only for the reason that we are still in the purely experimental stage. Contract patrol work was originated a year ago on the Somme. We were the first to adopt it; there is reason to believe that we shall be first in perfecting it. But the Boche has the inventive faculty full well developed; wherefore it behooves us to consider whether his scheme of a slow, heavily-armored, bullet-proof trench-fighter is not worthy of adoption.

Meanwhile it is quite clear that the Boche is pinning his faith to next spring's aerial offensive. It is also clear that he is laying his plans now, as he perforce must do. If we are to counter him, and do so effectively, we must also start to plan straight away. Otherwise we shall be in for a hard time next spring, and London, to consider only one aspect of the matter, will be no health resort. In war, as in physic, there is only one maxim that commands success: exterminate microbes before they attack you.

Some Notes on the Airscrew and the Problem of the Optimum Diameter.—By E. P. King, B.Sc. (Eng.), London.—A paper discussing the best diameter of airscrews for particular sets of conditions which are determined by the power and speed of the engine, the speed of the aircraft and the type of propeller used. Diagrams giving the efficiency curves, thrust curves, torque curves, etc., of a 250-hp. propeller accompany the article.

The Aeroplane (London), October 17, 1917

The Commander of the Defenses of London.—The Defenses of London are under the command of Maj.-Gen. E. B. Ashmore, C.B., M.V.O.

General Ashmore was born on Feb. 20, 1872, in London, and after a highly distinguished career in the Royal Regiment of Artillery he attained his majority on April 19, 1909. He learned to fly on a Bristol biplane at Brooklands, his certificate being No. 281, dated Sept. 3, 1912, so that as an aviator he is closely contemporary with General Salmond. He served as a G.S.O. in the Directorate of Military Aeronautics, and went to France with the R.F.C. at the outbreak of war.

On Nov. 18, 1914, he was gazetted temporary lieutenant-colonel, as a wing-commander, R.F.C., and later on was promoted to brigadier-general.

Aeronautics (London), October 17, 1917

The New High Command for the R.F.C.—On Oct. 12 the Secretary of the War Office made an announcement to the effect that "Lieut.-Gen. Sir David Henderson, K.C.B., D.S.O., having been deputed to undertake special work, has been lent for such service, and has thereby vacated his seat on the Army Council.

"The Secretary of State for War has appointed Maj.-Gen. J. M. Salmond as his successor as Director-General of Military Aeronautics, with a seat on the Army Council.

"Major-General Brancker, at present Deputy Director of Military Aeronautics, has been appointed to a command abroad, and for the present his place will not be filled."

Lieut.-Gen. Sir David Henderson, K.C.B., D.S.O., will live in history as the chief of the Flying Corps during the critical first three years of war and the years immediately preceding it. Born in 1862, he entered the Argyll and Sutherland Highlanders in 1882. In the South African War he was wounded at Ladysmith, and subsequently became Director of Military Intelligence. His connection with aviation dates back to 1911, when as Brigadier-General Henderson he took his pilot's certificate at Brooklands. In 1912, the period of the Military Trials on Salisbury Plain, he took over the command of the Royal Flying Corps, then recently formed, and nominally became Director of Military Training at the War Office. A year later he was appointed Director-General of Military Aeronautics and colonel commanding the Royal Flying Corps.

Maj.-Gen. John Maitland Salmond, C.M.G., D.S.O., who succeeds him, was born on July 17, 1881, son of a well-known military family. From Wellington he passed in 1901 into the Royal Lancaster Regiment and received his captaincy in 1910. He served through the South African War and other minor campaigns, and took his pilot's certificate in 1912. The same year he was appointed instructor at the Central Flying School at Upavon. On May 31, 1913, he was gazetted squadron commander, and for the first two years of the war served with distinction in France and Flanders as wing commander, winning the D.S.O. and three mentions in dispatches. Successively lieutenant-colonel and brigadier-general in 1916, he was gazetted major-general on June 22, 1917.

News of the Fortnight

Appointment of Aircraft Board Expected

According to Howard E. Coffin, acting chairman of the new Aircraft Board, the three civilian members will be announced within a day or two. Already the Army and Navy representatives have been announced by the Secretary of War and the Secretary of the Navy, respectively, and it only remains for the President to appoint the three civilian members. Rumor has had it for some little time that Richard F. Howe, formerly treasurer of the International Harvester Co., has been appointed as one of the three civilian members. On Nov. 20 the New York *Times* printed a Washington dispatch, in which it was stated that this appointment had been made. AVIATION AND AERONAUTICAL ENGINEERING then communicated with the White House office on the long distance telephone and is informed that the civilian appointments have not as yet been announced, and that no suggestion as to who they may be can be made at this time. The work of the board, which is to supervise the production of airplanes and accessories, is, however, still going forward under the old board, of which Mr. Coffin is chairman.

Mr. Coffin announced recently that the work of the board was keeping up to schedule, and that fine progress was being made. While no Liberty engines are yet being delivered in quantity, several plants are turning out a few each week, and by January it is expected that both engines and airplanes will be manufactured and delivered in large quantities.

"Preparations for the training of the American aviators after they leave the ground schools are also progressing exactly according to schedule, for the construction of the big training schools and flying fields in various parts of the United States which are not already in full operation are nearing completion," said Mr. Coffin. "Whereas a number of these partly trained student aviators have been sent abroad for their final instruction in the past, in the near future they will probably all be trained in this country," he continued. It was learned that instructors from the front will return here, or be detailed, to teach them all the finer points of flying, observing and fighting in the air.

There seems to be no way in which to estimate the number of student aviators training in this country, or the number sent abroad, but it is fair to assume that the Signal Corps has kept pace with the schedule set early in the year in the same manner that the Air Board has kept up the production of airplanes.

It was learned from the Council of National Defense that the new Motor Car Industry Committee is doing good work, and that the purpose of this committee, like that of all the industrial committees, is to keep idle manufacturing plants or industries not producing to full capacity in touch with the needs and demands of the Government. Where Government work is being taken over it was being done gradually in order that no hardship on the plant or company will be worked so that the decrease in the general or regular productions will not be felt in the market. In other words, a gradual conversion is being carried out so that eventually an increased percentage of the Government work may be handled without curtailing the regular output of a certain article or type of article. Little trouble with any of the Government production is anticipated, and even now the industrial committees report that the work is ahead of the program.

Foreign Airplanes on Exhibition

Among the exhibits at the "Hero Land" bazaar, which opened at Grand Central Palace, New York, on Nov. 17, is one of the fifty-four German airplanes brought down by the late Capt. Georges Guynemer, the famous French aviator. Several French planes, the wreckage of a Zeppelin which tried to bomb Buckingham Palace, a Fokker airplane brought down on the western front by a British aviator, and exploded and unexploded air bombs are also on exhibition.

Wright Monument in France

The committee appointed before the war to arrange for the erection at Le Mans, France, of a monument to Wilbur Wright, has decided to proceed immediately with the work. It is understood that the monument will be erected on the Camp of Auvours, where Wilbur Wright first demonstrated, in 1908, his airplane to the French public.

Advisory Committee Opposes Aero Shows

The National Advisory Committee for Aeronautics is opposed to the holding of aeronautical expositions during the period of the war. By formal resolution, it has approved the action of the Aircraft Board, which has announced that as a matter of general policy in view of the military situation it does not encourage the holding of any expositions of aircraft for the duration of the war.

For military reasons no developments of new types of engines or planes can be exhibited and the inevitable distraction of interest on the part of manufacturers would not be in the interest of the military departments.

The National Advisory Committee for Aeronautics gave the question careful consideration at a recent meeting, after which the following resolution was passed:

"Resolved, That the action of the Aircraft Board on the subject of aeronautical expositions during the war be approved by the National Advisory Committee for Aeronautics and that the Aircraft Board and the Manufacturers Aircraft Association be notified of this action."

National Committee on Civil Aerial Transport

The National Advisory Committee for Aeronautics announced on Nov. 20 the establishment of a Committee on Civil Aerial Transport. This committee supersedes the former committee on Aerial Mail Service and has far broader scope and functions.

The functions of the Civil Aerial Transport Committee will include, in addition to those formerly exercised by the Committee on Aerial Mail Service, the problems connected with the application of aircraft to civil purposes, the utilization of military airplanes and aviators after the war for such purposes, and co-operation with similar organizations of other nations.

The organization of this new committee is as follows:

Dr. W. F. Durand, chairman, chairman of the National Advisory Committee for Aeronautics.

Dr. S. W. Stratton, secretary of the National Advisory Committee for Aeronautics, and director of the United States Bureau of Standards.

Prof. Charles F. Marvin, chief of the United States Weather Bureau.

Lieut.-Col. V. E. Clark, Signal Corps, U. S. A.

Lieut. Commander J. H. Towers, U. S. N.

All of the above are members of the National Advisory Committee for Aeronautics.

In accordance with regulations, which have been approved by the President, additional members may be added from time to time as the work of the committee develops.

Comprehensive plans will be formulated as soon as practicable, but it is not planned to divert agencies of military value to the development of civil aeronautics until after the war.

Lloyd George on the Airplane Situation

Addressing members of the American War Mission and his followers among the leading representatives of the British Government at an historic conference held in Downing Street, on Nov. 20, on the prosecution of the war, Premier Lloyd George emphasized the importance of the American shipbuilding and military programs.

Dealing with the airplane situation, the Premier said: "Command of the air in the battle line is almost as essential as command of the sea. The people of the United States possess to an unusual degree the qualities of enterprise and daring necessary to the creation of successful aviators. The American climate also lends itself to the development of the air service, because it is clearer and more equable than the climate of the British Isles. This is of special value, because the training of pilots, the creation of flying units and the building of aerodromes are as essential to the creation of an air service as the building of airplanes themselves."

Liberty Engine Breaks Auto Record

Ralph De Palma, veteran auto speed driver, made a new record on Nov. 16, at Sheepshead Bay Speedway, New York, when he drove a Packard car fitted with a Liberty engine a distance of 633.12 miles in six hours, breaking the record for that time.

How to Prepare for Overseas Service

An Army officer now on foreign duty has written a letter home suggesting a number of things which should be done before embarking and listing the more important items which should be carried along.

His first suggestion is to settle one's business affairs. Following which he remarks that an application should be filed for the Soldiers' and Sailors' Insurance, the study of French begun, and a checking account with an European house established. A code address should also be listed before leaving this country, and all equipment should be carefully and conspicuously marked. A total of 250 lb. may be carried by officers.

In view of the prices of equipment abroad, it is advisable to secure certain things before undertaking a trip overseas. Leather, among other things, is expensive abroad, but, strange to relate, he states that the "Sam Browne" belts are only $6 and $7 in Paris. The best "trench" coats in England and France, however, are reported to cost $35, while whip-cord breeches with doe-skin knees average $6. In general, a dollar in United States money represents 5.70 francs, or 4 shillings, 2 pence. Probably American troops will be paid in French money.

En route, continues the voyageur, caps are convenient, though not worn over there; in fact, only campaign hats and steel helmets are authorized. Pistols are kept much cleaner and safer if boxed for the trip.

A list of the officer's suggestions as to equipment follows: Officers' locker or trunk (wardrobe steamer-trunks are handy), hand-bag, with toilet articles, trench mirror, wrist watch, pocket flash-light, flint, wheel and tinder lighter, canned solidified alcohol, and tobacco for two months, a short winter coat, knee-laced waterproof boots, boot and shoe laces, fleece-lined gloves, extra hat, shoes and mess outfit, plenty of handkerchiefs and socks, a cable code book, coffee (tea is plentiful), chocolate, soup and beef tablets or a few cans of soup, face and laundry soap, a few books, plenty of United States stamps, a good fountain pen, blank forms and stationery and a wash basin.

Lord Northcliffe on Aircraft Production

In an interview Lord Northcliffe says he will return to the United States as head of the British War Mission after the Allied conferences and trip to the fronts.

If the British Government desired, he said that he would devote much of this time to the question of aircraft production in the United States, and added:

"My great fear is that the American output will exceed the possibilities of training officers and mechanics. Americans are willing to make any type of engine we ask, in addition to their own Liberty engine."

Assigned to Joint Technical Board

Col. H. H. Arnold and Maj. Harold S. Martin, Signal Corps, have been appointed members of the Joint Army and Navy Technical Aircraft Board, in place of Brig. Gen. B. D. Foulois and Maj. Henry W. Harms, Signal Corps.

New German Rubber Bomb

Recent dispatches from the fighting front tell of a new rubber-based bouncing bomb recently used by German aviators. The bombs are provided with a resilient base of leather, rubber and rope, which makes them bound upward into the air after striking the ground. The special fuse attached causes the bomb to burst when it has reached the pinnacle of its bound, about six feet in the air.

Butts of these aerial bombs, which have been picked up, show that all are provided with a base of synthetic rubber and are wrapped around and around with rope, making them resilient.

The bombs are weighted so that the end with the rubber pad will strike the ground first. The impact with the earth sets in motion the time fuse, which detonates the bomb a fraction of a second later when the bomb has bounded into the air.

Air Mail for U. S. Troops

Aerial postal service between the American troops in France and their British and French comrades, with an extension to Algeria and Morocco, is planned by the municipal post authorities at Lyons.

A commission has been appointed to study the question of routes and sailing times for the service.

Swear Allegiance at Standard Plants

Men and women employed by the Standard Aero Corp. took the oath of allegiance to the United States recently.

Realizing that the various fires and other destructive acts committed by enemy aliens constitute a deadly peril to this country's war preparations, Harry Bowers Mingle, president of the corporation, first instituted a rigid inquiry into the nationality and antecedents of every one of his thousands of employes, and then ordered that every man and woman of them should take the oath of allegiance. The oath was administered by a public official, legally empowered to do so, to the office force and executives, as well as the factory employes.

The Standard Aero Corp. has just moved a major portion of its help and machinery to the new plant at Elizabeth, N. J.

In addition to the original place which existed at the time the purchase was made of the original property from John Stevenson Car Works, a new two-story aircraft assembly building has been put up, running the full length of the shops; barracks for the men have been built, ready to hold two hundred and fifty men, each separately in a room provided with shower baths, etc.

There is under construction an administration building which will be completed within a month and which will house all office help and contain the principal executive offices, etc. Within a month the immense restaurant and lunch room of the company will be running, where all the employes will be fed from the company's kitchen.

Coincident with the moving of the main portion of the operating forces to Elizabeth, the Standard Aero Corp. has found it necessary to organize an additional company under the name of the Standard Aircraft Corp. under the laws of the State of New York.

On and after Nov. 1, 1917, these two organizations, under practically the same management, but with their enlarged facilities and redoubled energy, will divide their activities as follows:

The Standard Aero Corp. of New York, operating at Elizabeth, will continue as an engineering and experimental organization, doing primarily aircraft engineering and experimental work, while The Standard Aircraft Corp. will be the production or manufacturing company, operating at the Plainfield and Elizabeth plants.

A number of changes in personnel have taken place with the new organization, which are as follows:

Clifford Talbot, formerly superintendent of the New England Westinghouse, has taken charge as works manager of all plants.

E. E. Pennewill, formerly superintendent of the Standard Aero Corp., becomes general manager, and C. V. Bradford, formerly general manager, becomes vice-president.

The headquarters and main offices of the company will be at Elizabeth. The company expects to push to the uttermost its work by employing women help as one of the best means of expediting aircraft production.

Air Minister for Great Britain

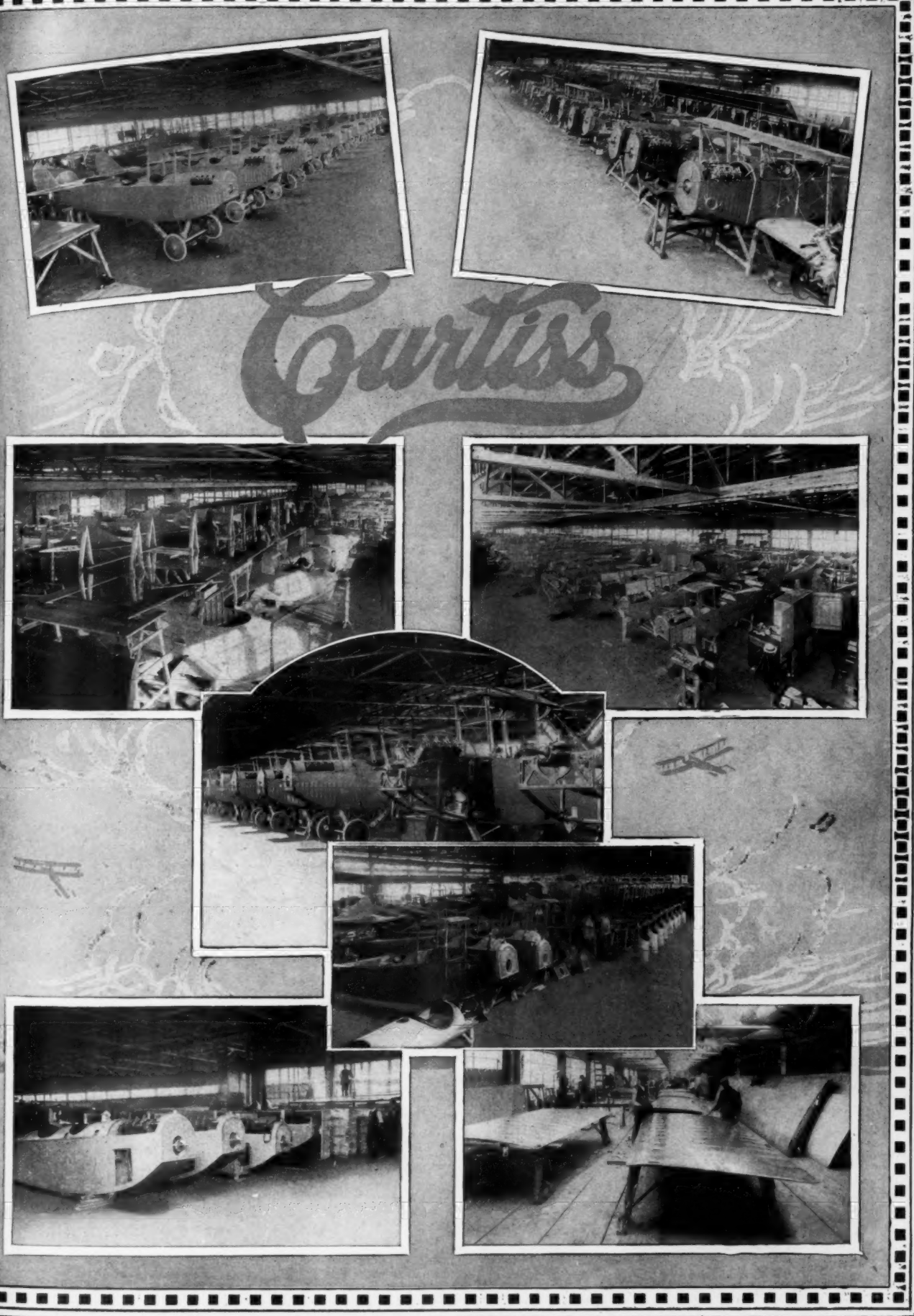
It is reported that a bill for the establishment of an air ministry will be introduced in the British House of Commons in a few days. It will provide for co-ordination in several branches of the work of the naval and military air services and the air board. The ministry will assume complete control of the new arm gradually.

A central organization policy and a central organization supply will be established. This bureau will be given power over discipline and pay. Lord Northcliffe was offered the position of first air minister, but declined. His younger brother, Lord Rothermere, then accepted the post. Lord Rothermere is the chief proprietor of *The Daily Record and Mail* of Glasgow and of the *Leeds Mercury*.

Sweden to England Via the Air

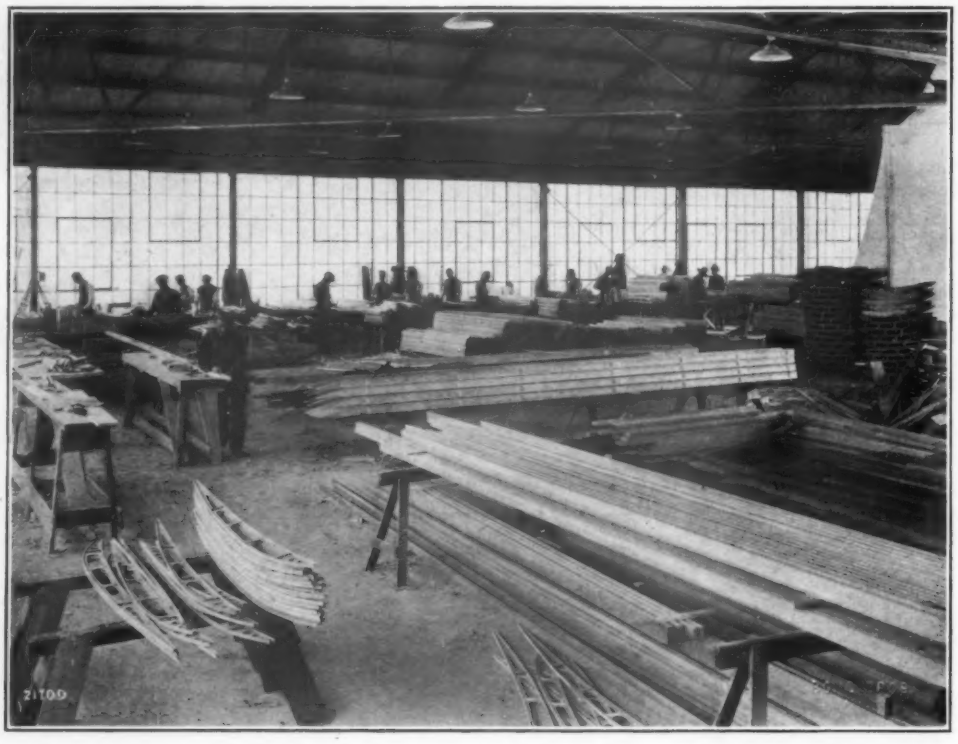
An airship passenger-and-mail service between Sweden, Finland and England has been projected at Stockholm, Sweden, according to a special report received by the Department of Commerce, Washington, D. C.

A Swedish company has been incorporated with a capitalization of $536,000, to organize and operate this line, and it is reported that airships designed to carry six passengers and a large amount of mail are under construction.



THE CURTISS AEROPLANE COMPANY, BUFFALO, N. Y.

America Trans Oceanic Company, 280 Madison Ave., New York City, New York Agents



"SOMEWHERE IN THE ROGERS SHOPS" where thousands of wood parts for use in Airplane Construction are handled every day.

Lower Cuts show two methods of Measuring a Wing Rib Cap Strip, the old Two Foot Rule way and the modern Rogers way of Measuring with a Rogers Fig. 13 Double Ended Limit Gauge ground accurate to .0001 of an inch with a tolerance limit of plus or minus 1/64", which is the accuracy called for on this particular job.

Rogers Accuracy Has Been the Foundation of Rogers Success

ROGERS CONSTRUCTION COMPANY, AIRCRAFT PARTS
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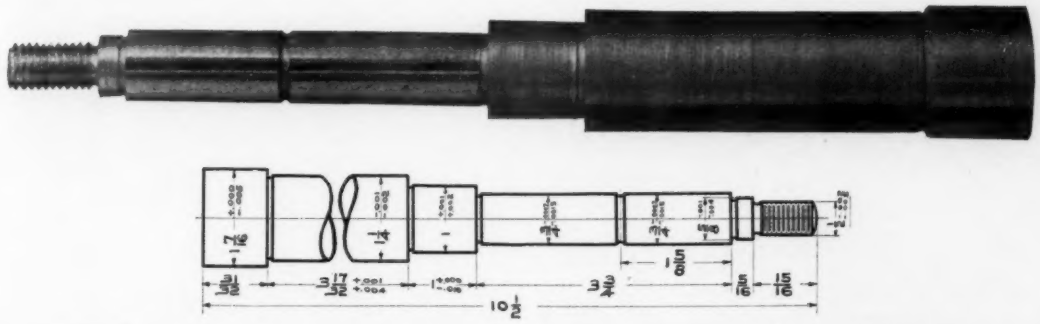


Three Times as Many Shafts per Day on the No. 4 Universal Turret Screw Machine

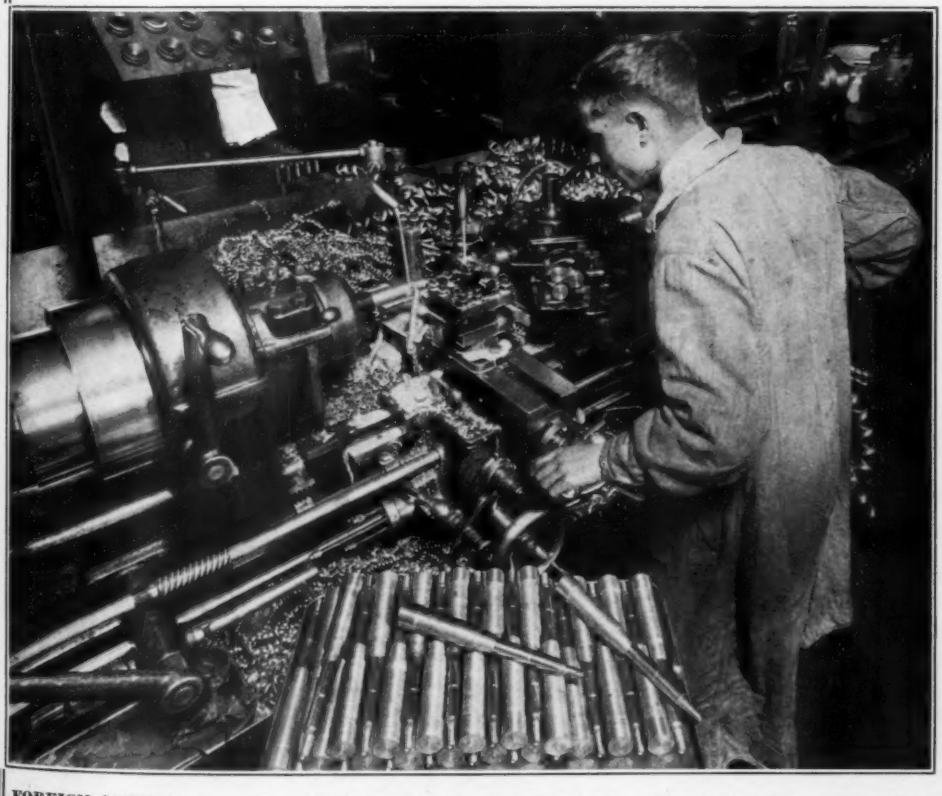
Heretofore the best time recorded for machining this pinion shaft on a turret lathe without a carriage has been 30 minutes each or 20 per day.

But when transferred to the No. 4 with its instantly changeable simultaneous turret-and-carriage operation the time was reduced to 10 minutes each or 60 per day.

Such achievements are common occurrences where any W. & S. machines are in use. On the 3-A Hollow Hexagon Turret Lathe Gnome type engine cylinders—previously a 35-hour job—have been produced in 2 hours and 47 minutes from 47 lb. forgings. Again on the 3-A a 21¾" solenoid plunger previously made on engine lathes at the rate of 2 per day were made in 35 minutes each. On the 2-A a 17⅜" cast iron sleeve—a job they said was impossible on a turret lathe—was made in 30 minutes against its previous time of 2 hours on an engine lathe. Hundreds of other time-saving instances await the inquiry of those interested in meeting emergency demands for record-breaking quick production.

Because of their close working and extraordinary accuracy no less than their unprecedented speed all W. & S. machines are unquestionably the most economical installation for airplane plants.

Inquiries will be promptly answered, by mail or in person, if you will send blueprints with rough and finished samples to our nearest office.



While the ½", ⅝" and ¾" diameters are being turned and threaded by the hexagon turret, the 1", 1¼" and 1-7/16" diameters are being turned by the square turret on the carriage.

THE WARNER & SWASEY COMPANY

CLEVELAND, OHIO, U. S. A.

TURRET LATHES—TURRET SCREW MACHINES—BRASS WORKING MACHINE TOOLS

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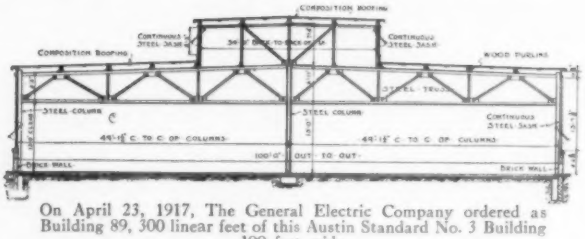
An Austin Standard Factory-Building Built for The General Electric Company at Schenectady, N. Y., in Thirty Working-Days

Austin Standard Factory-Buildings



On April 23, 1917, The General Electric Company ordered as Building 89, 300 linear feet of this Austin Standard No. 3 Building 100 feet wide.

Building No. 89 of The General Electric Company at Schenectady, N. Y., on May 19, 1917, 21 working-days after day of order. The steel is more than half up and the roof is going on.

Exterior of Building 89 of The General Electric Company on May 31, 30 working-days after the order. Finishing this building on time last June brought us orders for five more buildings for the same customer, all of which have been finished *on time or ahead of time*

Can be Occupied in 30 Working-days

YOU can move into a new Austin Standard Factory-Building in thirty working-days from the day you sign an Austin *Thirty-Day Guaranteed-Delivery Contract.*

This is possible because the Austin Company—subject to prior sale—actually has all the materials in stock ready for immediate shipment.

The General Electric Company, The Dayton Metal Products Company, the United States Government, and many others have already taken advantage of Austin 30-day Guaranteed-Delivery of completed floor-space.

You can close the contract for which you are negotiating, buy your machinery for delivery at a given date, and buy your building on the same basis: from a catalog, at a given price, for guaranteed delivery, ready for occupancy in thirty working-days.

Write, phone or wire the office nearest the proposed work.

The Austin Company

INDUSTRIAL BUILDERS

Cleveland, Ohio

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If the Goggle you wear is not RESISTAL you take an unnecessary chance. RESISTAL cannot shatter.

On Nov. 23rd, 1917, the Navy Department adopted RESISTAL for aviators' goggles and masks.

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In addition to the Army standard frame RESISTAL is now made in a variety of frames for aviators' goggles and masks.

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The new selective draft regulations prevent any man from 21 to 31 years old enlisting after December 15th. In order to complete your enlistment (be examined, accepted and take the oath), you should positively report to any recruiting officer before December 13th.

The War Will Be Won In The Air

AEROPLANE MOTOR MECHANICS

NOW BEING TAUGHT AT THE MICHIGAN STATE AUTO SCHOOL

A course in Aeronautics has been established, to train mechanicians for the Aviation Service. This will include thorough instruction and practice in building, running, and repairing aeroplane motors, repairing of planes and other parts; lectures in the theory of flying, history of aviation, construction of propellers, fuselage work, including metal fittings, bracing, and wiring, wing construction, controls, landing gear and pontoons and the care of the entire machine.

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By special permission, the necessary equipment for thorough instruction has been secured from the Curtiss Aeroplane Company. A Curtiss expert will head the faculty. He is an authority on aero-motors and aeroplanes, as well as hydros and flying boats. He will be assisted by a competent staff of instructors, who have had over eight years of educational training along similar lines.

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The men who become trained aeroplane motor mechanics now will be big men in the aeroplane busines . Only a short ime ago the automobile business was starting. The men who got in then are now the Big Men. The aeroplane business is in its infancy. The war will give it a start. The men who train now will be Big Men too. The work is extremely interesting and will grow in interest as the business develops. Aeroplanes and Seaplanes will be used for every pu·pose. Trained aeromotor mechanics will always be in big demand.

Trained Aero Men Serve Their Country Best

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Aeroplanes, Hydroaeroplanes, Flying Boats, Aeronautical Motors.
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September 17, 1917.

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Michigan State Auto School, Detroit, Mich.

Dear Mr. Zeller:—
In accordance with our conversation I have asked the Sales Department to send you a collection of motor and aeroplane parts which you can use in connection with your aeroplane mechanics' school. You will find, I think, a sufficient number of parts so that you will have no difficulty in explaining to your students the general principles of construction and operation.

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Yours very truly,
THE CURTISS AEROPLANE CO.
F. L. Faurote, Advertising Manager.

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Students may enter our classes at any time. Write for further information, or come right to Detroit and start at once.

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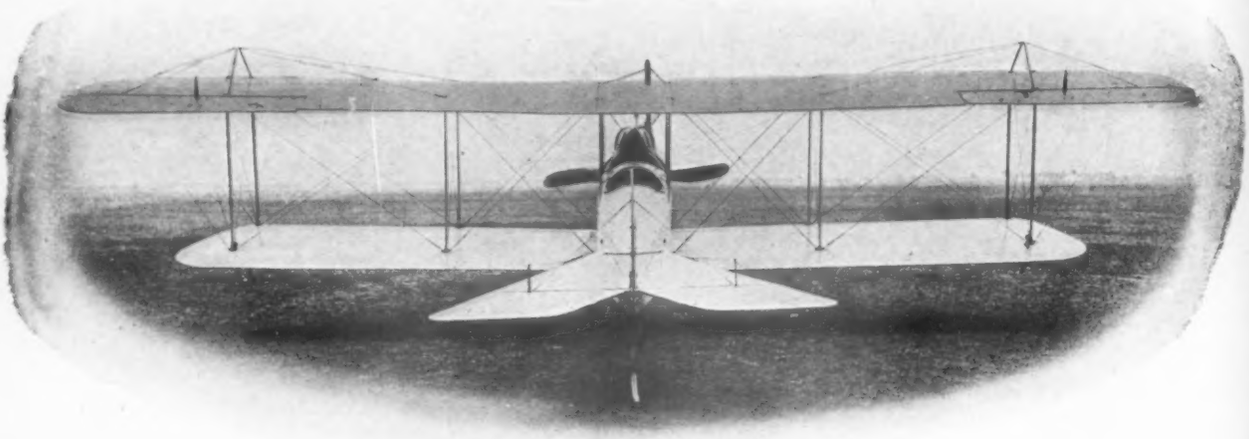

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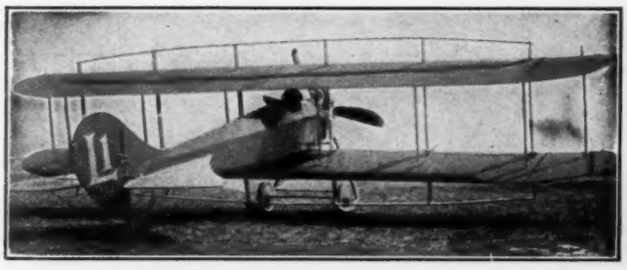

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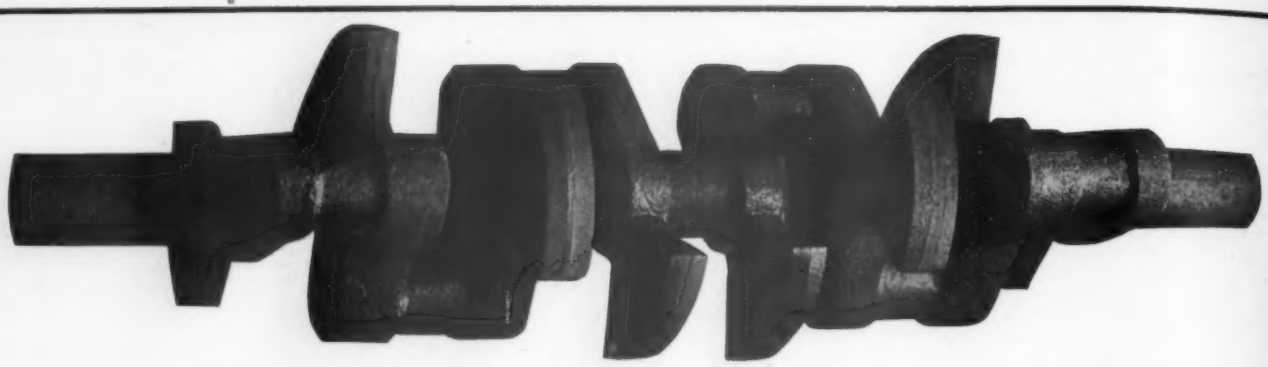

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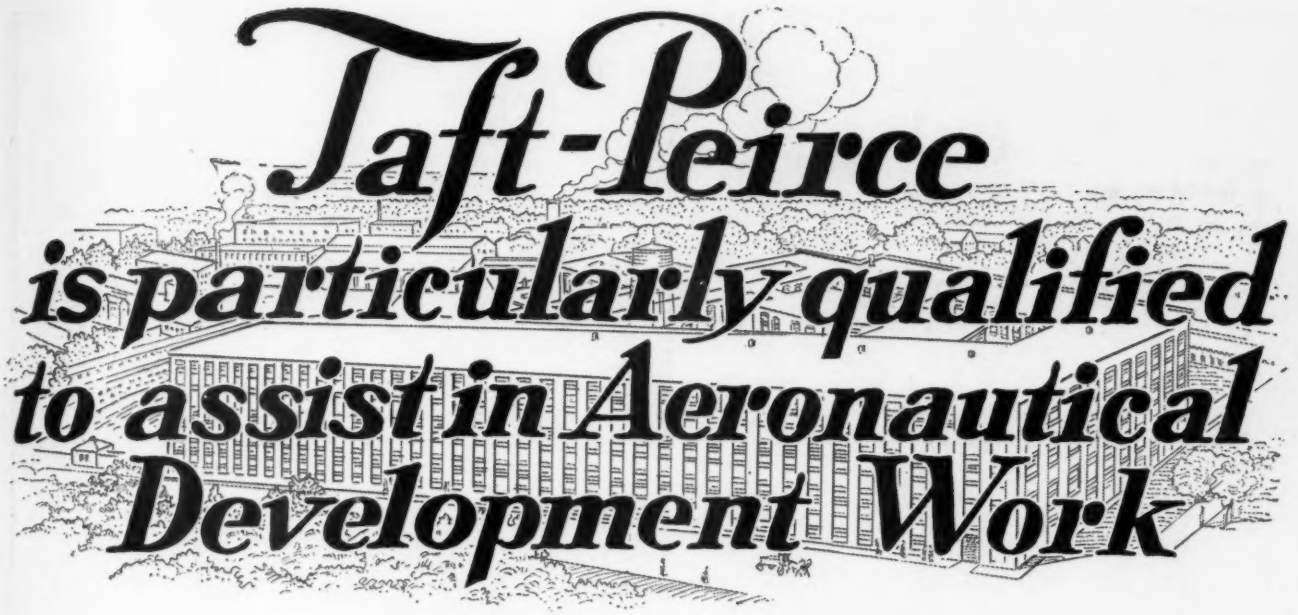

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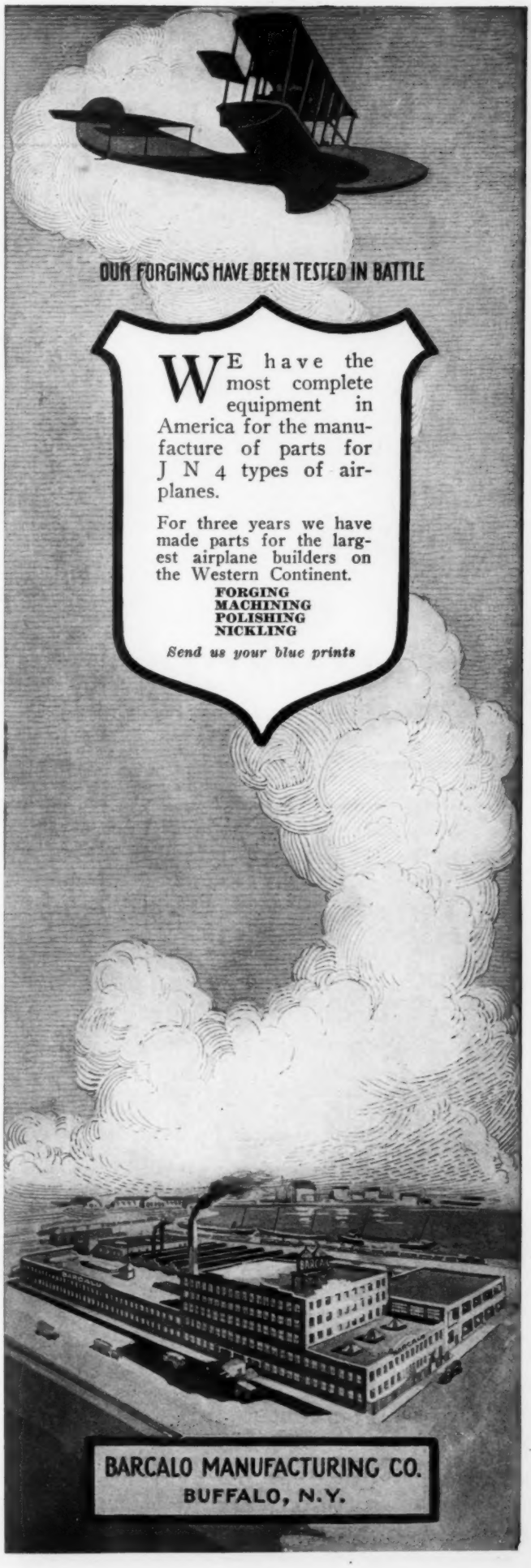
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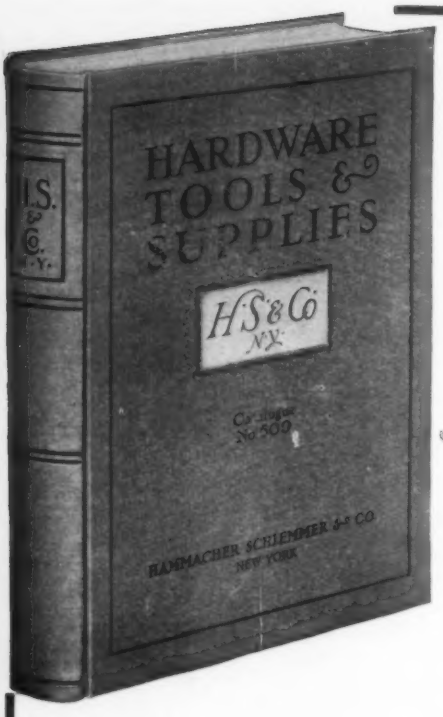

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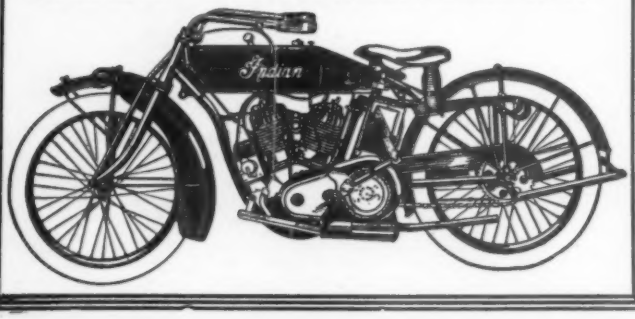

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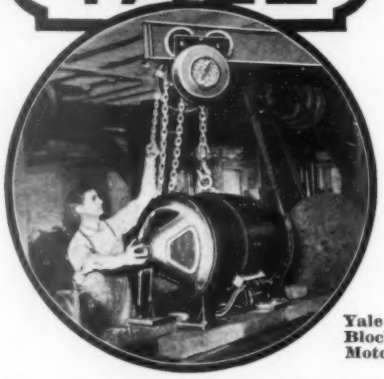

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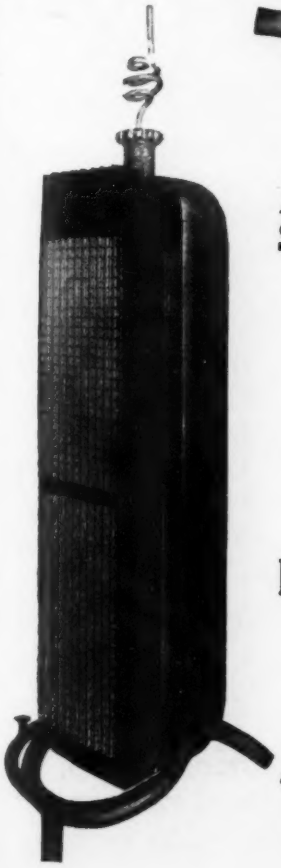

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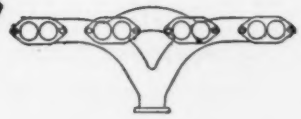

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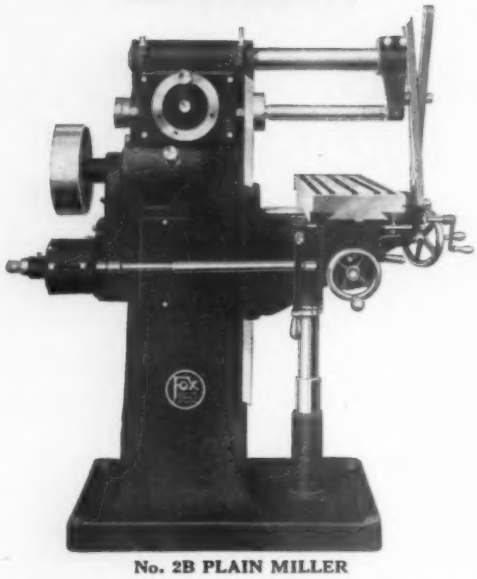

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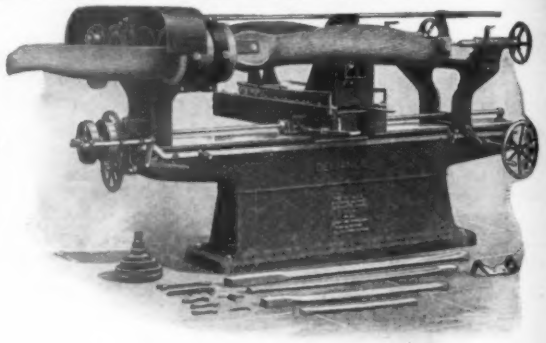

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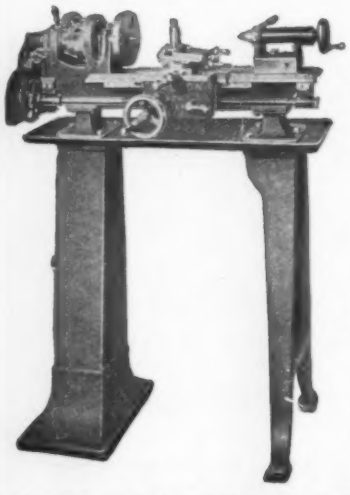

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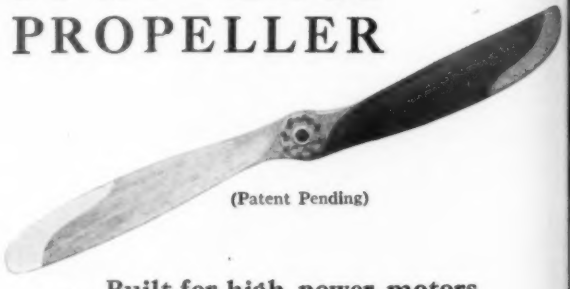

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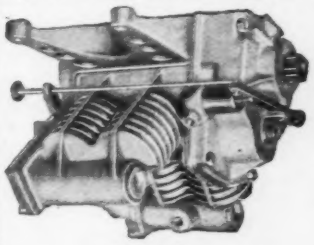

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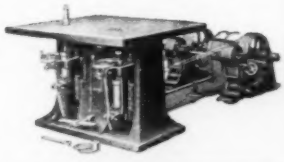

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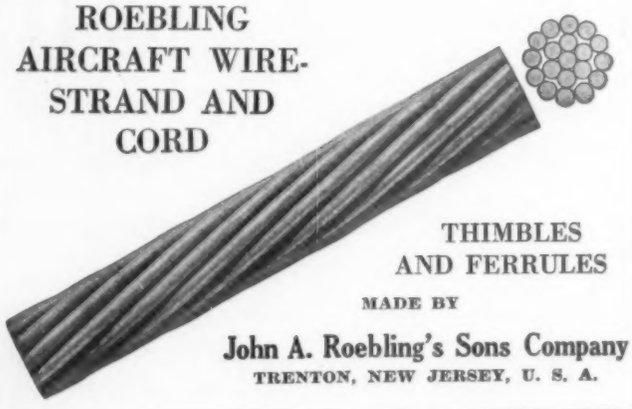

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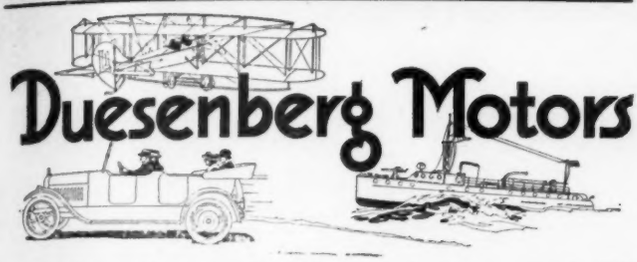

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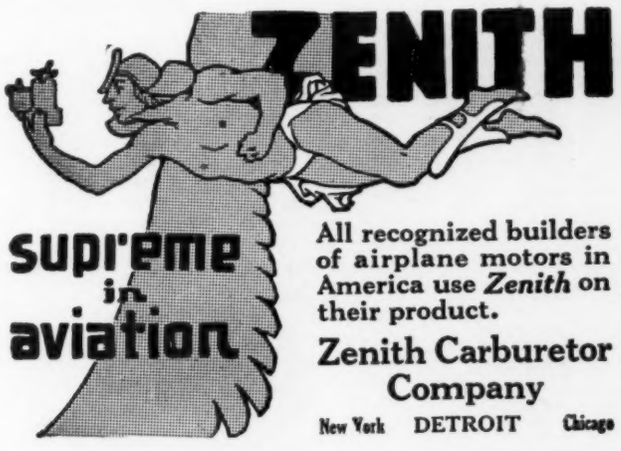

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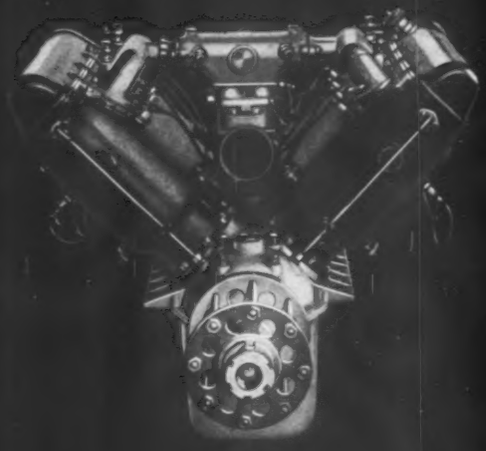

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